



Using Digital Tools to Analyse and Validate Sound Measurements

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Sound measurements are a key part of many acousticians daily work. Whether the purpose is to verify sound insulation in a new building, to investigate the source of annoying residential noise, or to provide input to a legal dispute, it is of great importance that the results can be trusted. However, there are a number of things that can go wrong when making measurements in the field. This article discusses common sources of error, both in measurement and evaluation, and gives examples how various digital tools can help us make sure these are caught before leading to wrong decisions. The suggested methods include logging third-octave band levels for each time step, recording audio for listening, and analysing spectrograms to identify disturbances even when third-octave band levels of sound source and disturbance overlap. The article also illustrates how a customised evaluation of reverberation time can improve transparency and reduce uncertainties, and at the same time allowing more flexibility in the measurement procedure. Finally, it is suggested how an automated handling of measurement data can reduce the risk of human errors and improve traceability, while also enabling the engineer to be solely responsible for fulfilling calculation standards instead of being dependent on third-party software. The latter can be of strategic importance, both to retain understanding of the standardised methods in the company, but also to react more quickly to changes in measurement or calculation standards.

1 Introduction

When measuring sound in any context it is vital that the results correctly represent the phenomenon that is of interest. Instructions for measurement procedure exist in standards such as ISO 16032, ISO 10052, ISO 16283 [1, 2, 3], etcetera, and following them will ensure that reasonable results are obtained in most cases. However, as both students of acoustics and professionals know, there are many things that can go wrong even when following measurement standards, for example background noise sources that were missed in situ, disturbances not noticed at all due to duty cycles coinciding with the object of interest, human errors in evaluation and data management, and many more. This article discusses some of these issues and proposes methods and tools, both existing and custom-made, to mitigate them. It also describes how these tools can improve measurement efficiency and allow deeper analysis.

2 Common sources of error in the field and after

Errors can occur anywhere in the process of measuring, evaluating and report writing. By following the measurement and calculation standards most of them can be detected before causing harm, but there can still be negative consequences, for example that less information is acquired from the measurement. A common example of this is when the background noise is dominating the measurement and the object of interest can then only be concluded to be lower than the background level, which may or may not satisfy the customer's needs. The most problematic source of error in field measurements is perhaps disturbances that are not detected either in the field or in evaluation, since they then can propagate to the customer and lead to incorrect decisions. This can easily occur if the source of the disturbance is time-dependent and happens to coincide in time with the object of interest, and thus not being present in background noise measurements. To detect these kinds of errors it is necessary to use more advanced evaluation methods than looking at global A-weighted and third-octave band levels. Examples of such methods are given in Section 3.3.

Another source of uncertainty exists in the use of so-called black box algorithms, that is algorithms that produce a result but give little or no insight in the calculation process. There is often a trade-off between ease of use and time consumption on the one hand, and transparency and control on the other, and commercially available software intended for field use quite understandably tends to lean towards the former. Consequently, there can be situations when the lack of insight hides an important phenomenon. One area where this is often the case is in reverberation time measurements in the field. The evaluation process is described well in ISO 3382-2 [5], and is simple at first glance, but when the algorithm is applied to field measurements from a wide range of signal and background noise conditions, as well as different room sizes and so called broken decays, it becomes much more complicated. Automating this evaluation, without letting the user review the decay curves and the corresponding linear regression lines, can result in values that have no relevance in the real world. In Section 3.2 it is described how the ISO-standard can be implemented in a transparent algorithm which allows the user to review and correct the decay curve for each frequency band and microphone position.

The calculations needed to obtain the single number quantities used in building acoustics are well described in for example ISO 717-1 [4] and are easily implemented in a spreadsheet software such as MS Excel. However, after a long day of field measurements the amount of data is often very large, making the management and calculations much more complex than in the simple case, and the risk of human error larger. Adding a tight time schedule for the report, which is often the case, there is a risk that documentation of the measurements is insufficient, making it hard to review at a later point in time. In general, it is our experience that if documentation format and methods vary between employees, the knowledge database can become less accessible and the risk of misinterpretation is higher. In this context it is beneficial to standardise and automate data management and calculations. A custom-made software tool for this purpose is described in Section 3.1.

3 Methodology and tools

3.1 Data management, analysis and calculations software

In order to improve measurement data management and minimise the sources of error described above, a tool¹ has been developed for carrying out the necessary building acoustic calculations. It is built on an open source platform of Python 3 [6] and relies on structured input data in an Excel file. The output is in its basic form another Excel file with the calculated data and the corresponding graph, as well as the unprocessed input data. This way, no vital data is hidden in the program and users can calculate by hand, using the raw data, to check validity or try out different scenarios. For example, studying the effect of sealing a leakage by eliminating a dip in a sound insulation curve caused by this leakage. Still, the programming approach allows more automation and other features such as writing graphs directly to a pdf file, report generation, and a graphic overview of all measurement data with the ability to do simple operations such as averaging, linear and logarithmic addition and subtraction, etcetera.

An example of the input data structure is shown in Figure 1 below. By formalising the structure for measurement data and metadata there is a consistency in documentation which greatly improves traceability. While a consistent documentation can be encouraged without the use of a program as suggested in this article, the fact that the program uses the metadata in graphs and reports, and thus saving time, is a strong incentive for the user to actually follow the structures even in stressful situations.

¹ The tools described in this article is not commercially available. The intent is only to describe how purpose-made software tools can benefit the acousticians working process.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	mätdatum	2020-02-06											
2	mätoperatör	FN											
3	beställare	Bygg AB											
4	skiljeyta												
5	mottagarrumsvolym												
6	konstruktion												
7	typ	ljudnivå				luftljud				bakgrund			
8	objekt	lgh 1001 vardagsrum				lgh 1101 vardagsrum till lgh 1001 vardagsrum				lgh 1001 vardagsrum			
9	rum	mottagarrum				mottagarrum				mottagarrum			
10	mikrofonposition	hörn		rum		rum						rum	
11	högtalar/hammarposition	-											
12	efterklangsfil	-											
13	Frq/Network 1/3-octave	Ch1	Ch1	Ch1		Ch1	Ch1	Ch1	Ch1		Ch1		
14	2017-03-29 16:22:22.000	NOR140	NOR140	NOR140_8197475	NOR150-NOR140_8197475	NOR150-NOR140_8197475	NOR150-NOR140_8197475	NOR150-NOR140_8197475	NOR150-NOR140_8197475	NOR150-1 2018-12-21 10-14-35			
15	6,30 Hz	51,9	51,8	52,4		35,5	47,8	36,8	46,3		41,4		
16	8 Hz	52,5	53	53,4		36,4	48,1	38,6	49,8		46,4		
17	10 Hz	52,4	54,3	54,9		37,8	53,4	40,6	53,8		46,8		
18	12,5 Hz	53,8	57,2	58		38,9	53,6	45,6	53		53,1		

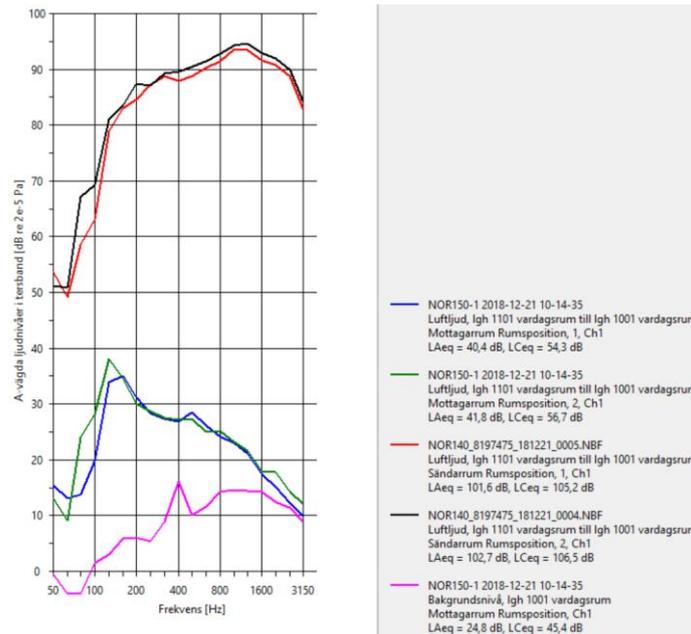
Figure 1: Structured input data with code words for e.g. measurement type in row 7 and microphone position in row 10.

The input data is interpreted using code words for measurement type, measurement object, microphone positions, etcetera, and the resulting groups of measurements are shown in a list, as seen in Figure 2. Different shadings illustrate how the measurements are grouped together, for example all measurements related to one sound insulation measurement. This way, it is easy to verify that the input data has been correctly interpreted. To help with analysis and to get a quick feel for the data some basic operations can be made, for example selecting rows for averaging, addition or subtraction (logarithmically or linearly).

	Typ	Objekt	Rum	Mätposition	Källa	Kanal
NOR140_8197475_170112_0004.NBF	Ljudnivå	lgh 1001 vardagsrum	Mottagarrum	Hörposition	-	Ch1
NOR140_8197475_170112_0005.NBF	Ljudnivå	lgh 1001 vardagsrum	Mottagarrum	Rumsposition	-	Ch1
NOR140_8197475_170112_0006.NBF	Ljudnivå	lgh 1001 vardagsrum	Mottagarrum	Rumsposition	-	Ch1
NOR150-1 2018-12-21 10-14-35	Luftljud	lgh 1101 vardagsrum till lgh 1001 vardagsrum	Mottagarrum	Rumsposition	1	Ch1
NOR150-1 2018-12-21 10-14-35	Luftljud	lgh 1101 vardagsrum till lgh 1001 vardagsrum	Mottagarrum	Rumsposition	2	Ch1
NOR140_8197475_181221_0005.NBF	Luftljud	lgh 1101 vardagsrum till lgh 1001 vardagsrum	Sändarrum	Rumsposition	1	Ch1
NOR140_8197475_181221_0004.NBF	Luftljud	lgh 1101 vardagsrum till lgh 1001 vardagsrum	Sändarrum	Rumsposition	2	Ch1
NOR150-1 2018-12-21 10-14-35	Bakgrunds nivå	lgh 1001 vardagsrum	Mottagarrum	Rumsposition		Ch1

Figure 2: Overview of measurement data as interpreted from the input Excel document. Each row can be reviewed alone, or together, and simple operations can be made between rows, e.g., averaging.

In the list of measurements shown above, one or more measurements can be selected for preview, in which the third-octave band data is plotted and the corresponding A- and C-weighted levels are written out. Each selected measurement is assigned a colour, and a legend summarises the metadata for each curve. In Figure 3 the sound level measurements corresponding to a sound insulation measurement is shown. This overview makes it easy to verify that sending and receiving room levels are not mixed up, and how much the background noise is affecting the measurement in different frequency regions. The frequency range can be set to the full audible range of 20 Hz–20 kHz or to the range 50 Hz–3150 Hz common to building acoustics in Sweden. The curves can be pre-weighted, and a table of numerical values can be shown.



Based on the input data structure and the inferred groups shown in figures above, standardised calculations can be made automatically. The user decides for each group of measurements how these should be evaluated, see Figure 4.

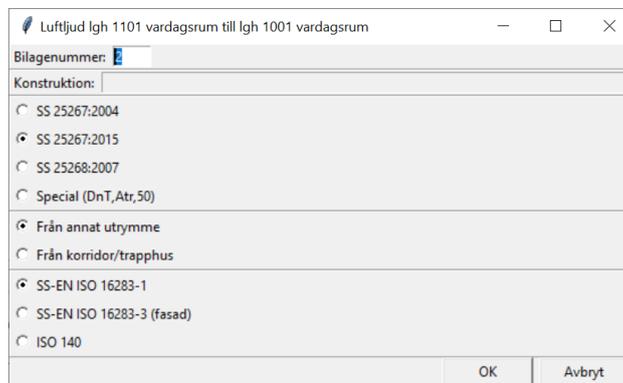


Figure 4: The user chooses by which standards to evaluate each group of measurements.

3.2 Transparent reverberation time algorithm

To mitigate the source of uncertainty related to closed “black-box” software for reverberation time measurement and evaluation described in the previous section, a program implementing the ISO 3382-2 evaluation procedure has been developed which allows the user to review the decay curves. As described above, disturbances occurring in field measurements often affect the linear regression, with the result of it not being representative of the room.

The input to the evaluation program is a wave file recorded in the measurement room during playback of a sequence of interrupted noise bursts. The program identifies and suggests starting points, and then calculates the decay curves for each microphone position and frequency band². Repeated decays for each microphone position are ensemble averaged by default, to obtain the smoothest decay curve. Starting points and decay curves can both be reviewed by the user. By clicking in the curve, the user can change the upper or lower limits for the regression to best represent the physical decay.

² Octave- and third-octave band filters are designed in accordance with IEC 61260-1 [7].

If there are impulse type disturbances appearing as peaks in the decay, it is often easy to see the “true” decay underneath and correct the regression to match that slope. This should of course be done with care and based on solid experience. The energy decay curves are displayed in the program as in Figure 5.

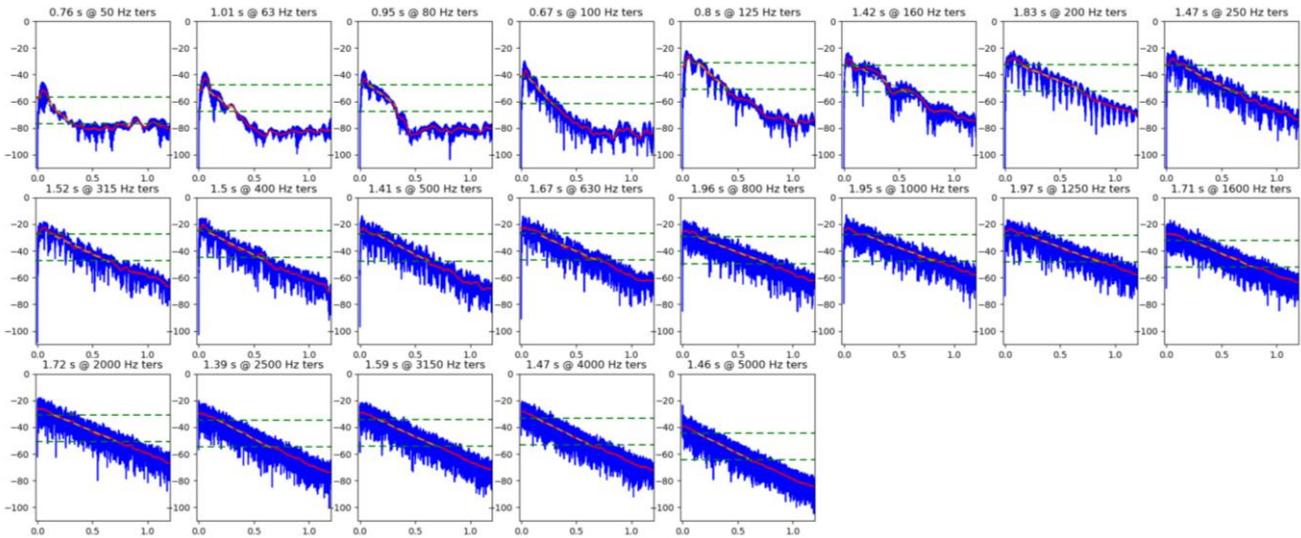


Figure 5: A summary of energy decay curves and the calculated linear regression lines for the user to review and correct.

After all microphone positions have been evaluated, the averaged result is presented together with the individual positions as in Figure 6. The dots represent the value in the 63 Hz octave-band, which is used in the low frequency method of ISO 16283-series standards. The octave-band value is calculated with a true octave-band filter as opposed to averaging of third-octave band values, making it less sensitive to errors due to low modal density and long filter response time; problems that often arise in small rooms with short reverberation times. The numerical data is written to text files which can be read by the program described in the previous section.

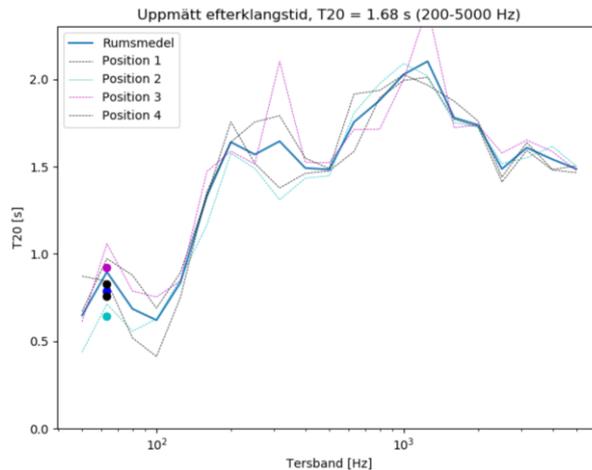


Figure 6: The calculated reverberation times in third-octave bands as well as the 63 Hz octave-band (dots). Average (solid line) together with individual microphone positions (dashed lines).

3.3 Analysis using existing tools

In addition to the use of purpose-made tools as described above, a lot can be done to increase accuracy of measurements using existing tools. Examples of this are given in the sections below.

3.3.1 Continuously logged third-octave band levels

Measuring sound from a stationary source, it is tempting to use global values measured during the source's active and inactive cycles. While this is a quick way to get a value for the source and background levels, there is a risk that time-varying disturbances are active at the same time as the measurement object and thus being hard to detect when reviewing the measurements. One way to avoid this is to save third-octave band levels for each time step. With a stationary source, any significant variation³ must then be due to disturbances. To further help analysis, the measurement can be made continuously, starting before and ending after the active cycle of the source of interest. It is then apparent when the source is activated and how much variation that is to be expected from each part of the cycle.

3.3.2 Audio recordings

When the characteristics of the sound source of interest and potential disturbances are not fully known it is useful to record an audio signal in parallel to the measurement. This way, any sound event can be reviewed by listening and deemed as either relevant or irrelevant. The state-of-the-art sound analysers have a very large signal to noise ratio, making it possible to record almost all commonly occurring sounds without overload, with no adjustment of input gain needed. Afterwards, a gain can be applied to facilitate listening. The recordings can also be processed further with for example a lowpass filter to highlight a frequency area of interest and to remove distractions. However, a backup of the original recording should always be kept.

3.3.3 Spectrograms

While audio recordings are helpful for identifying sound sources, there are some issues. For one thing, an audio recording alone does not provide a very good overview, as it takes time to review. Another issue is masking, which, being an inherent property of our hearing, cannot be avoided. These problems are solved by also studying the spectrogram of the recording – the FFT of the time signal evaluated in chunks (so called windows), providing a 2-D time-frequency graph with sound level represented by a colour scale. The relation between sampling rate of the signal and window size determines the frequency and time resolution of the graph. The window size should be chosen based on the source characteristics; it is often useful to try many settings and see which is most suitable for each situation. The frequency range of interest can be zoomed in on to give a better view.

A large benefit of this evaluation method in addition those already mentioned is that different sources often have very distinct visual patterns, allowing our brain's very efficient pattern recognition system to work. By working with spectrograms for many source types on a regular basis, an experience can be built up allowing the consultant to more effectively categorise sound sources. In Figure 7 and Figure 8 below it is exemplified how different source characteristics can be recognised and used to distinguish two sources with closely related frequency content. The washing machine centrifuging in the first figure has a very characteristic appearance with stationary and linearly rising sections and pronounced overtones, while the excavator noise has a typically exponential rise and fall and no overtones (recorded indoors far away from the source). Note that these patterns, especially the one of the excavator noise, would be much less pronounced and hardly recognisable in a third-octave band spectrogram, which is sometimes used.

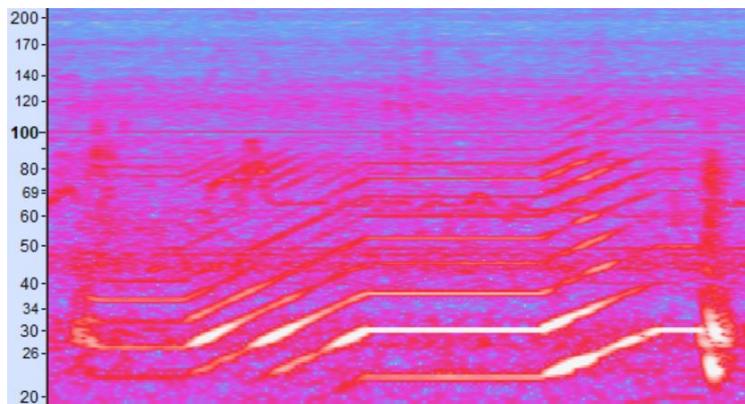


Figure 7: Washing machine centrifuging noise. Spectrogram of the audio signal recorded in the underlying apartment. $F_s = 12$ kHz, $N = 32768$, $\Delta f = 0.4$ Hz. X-axis is time, spanning 90 seconds, and y-axis is frequency in Hz.

³ Except spatial variations due to a moving microphone.

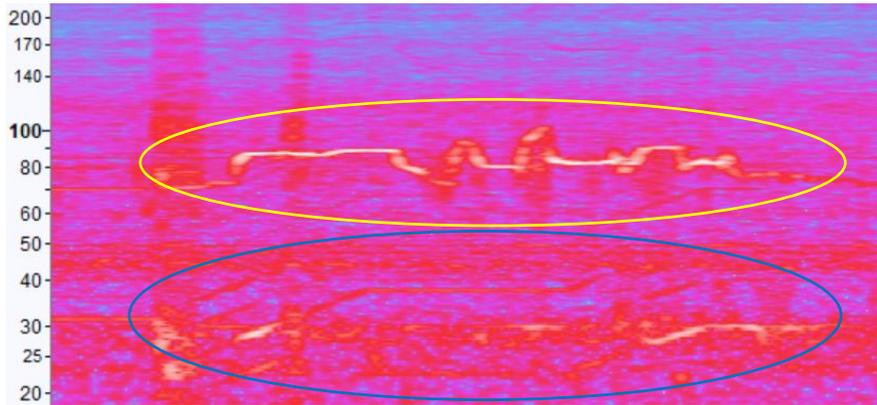


Figure 8: Excavator noise (yellow oval) overlaying barely visible washing machine centrifuging noise (blue oval). $F_s = 12$ kHz, $N = 32768$, $\Delta f = 0.4$ Hz. X -axis is time, spanning 120 seconds, and y -axis is frequency in Hz.

In both examples above, the lines corresponding to the respective source are continuous. This is to be expected from tonal engine noise, which is highly dependent on the RPM, since the RPM is continuous (except when shifting gears). The observation is important, as it allows us to better distinguish different sources from each other, even when they are overlapping in time and frequency, by following the lines. See Figure 9 below, where an excavator tone around 80 Hz is very close to one of the overtones of the washing machine in its stationary part. Listening to the recording, this would be very hard to discern, while it made a 3 dB difference in the 80 Hz third-octave band, in this case the difference between passing and failing noise level requirements.

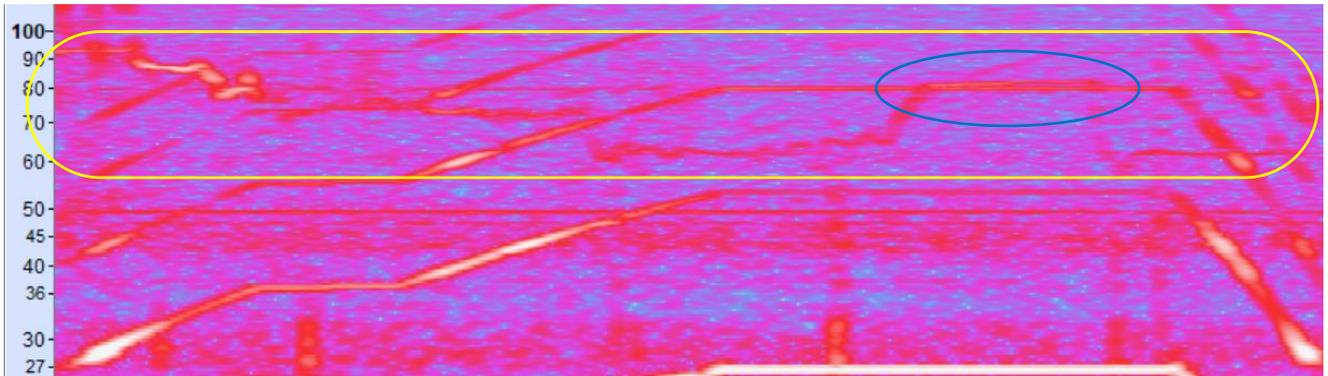


Figure 9: Excavator noise (yellow oval) can be distinguished from washing machine overtone even with minimal separation in frequency (blue oval). $F_s = 12$ kHz, $N = 32768$, $\Delta f = 0.4$ Hz. X -axis is time, spanning 100 seconds, and y -axis is frequency in Hz.

4 Summary

This article suggests how existing as well as custom-made tools and methods can help the consultant make more accurate analyses, facilitate traceability by standardising documentation, and reduce risk of errors in data management by automating calculations. It is described how to make use of FFT-spectrograms to effectively identify sound sources lying closely together in time and frequency, based on knowledge of the respective source characteristics. Two custom-made software tools are also presented; one used for measurement data management, analysis and calculations with focus on reducing human errors in the evaluation process, and one used for reverberation time evaluation with focus on transparency and reducing uncertainties related to disturbances commonly occurring in reverberation time measurements.

References

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