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Acoustic labels as a simple, easy-to-understand visual representation of the acoustic suitability of unconventional spaces

Kristian Jambrošić*, **Marko Horvat**

University of Zagreb, Faculty of Electrical Engineering and Computing, Zagreb, Croatia.

*kristian.jambrosic@fer.hr

Abstract

Instead of building many dedicated spaces that are acoustically optimised for specific types of events, many municipalities are forced by financial constraints to use multi-purpose halls and/or unconventional spaces as venues for a variety of different events. Depending on immediate needs, many public spaces are used as conference or lecture rooms, as well as venues for other speech-based events, but also as venues for unamplified or amplified musical performances, exhibition spaces, cinemas, theatres, etc. Many historic buildings are also frequently used in this way due to their attractiveness to visitors and their historical and cultural significance. In all these cases, the acoustic suitability of a space for a particular type of event must be investigated and determined. Many objective room acoustic parameters have been developed and are commonly used to evaluate the acoustic quality of both performance spaces and ordinary rooms. These parameters are not necessarily intended for the evaluation of unconventional spaces or spaces that are used temporarily or occasionally as performance spaces, e.g. an industrial hall used as a theatre, or a stone atrium used as a concert venue. Nevertheless, a rough rule-of-thumb evaluation can be made using these parameters to assess the acoustic suitability of such unconventional spaces for certain types of events. To help non-experts understand the results of such an evaluation, simple methods of visually representing the results are proposed, leading to a kind of acoustic label describing the acoustics of a room, similar to a product label describing a product by listing its main characteristics, or an energy label as the indicator of the energy efficiency of a product. A crude version of this approach has already been used to assess the suitability of several historic and contemporary spaces for different types of events, and is now being refined and extended.

Keywords: room acoustic parameters, acoustic suitability, acoustic quality evaluation.

1 Introduction

Room acoustics is one of the most, if not the most researched field of acoustics since it is experienced and evaluated by anyone having normal hearing. Therefore, people tend to have clear opinions about the quality of acoustics of rooms and spaces, based on life-long experience. The amount of research conducted in room acoustics is best illustrated in review papers such as the one made in 2017 on the influence of room acoustics on human performance [1], with a total of 313 references to corresponding research!

There is certainly no lack of room acoustic parameters defined to help acousticians evaluate the quality of existing spaces, or to design new venues with optimal acoustics for their intended use. For various reasons, many researchers introduce new parameters that better correspond to some specific room acoustic feature. At the same time, the well-known room acoustic parameters are sometimes used in other applications, e.g. in evaluation of the comfort of outdoor spaces [2].

There are numerous recommendations for optimizing room acoustics that define the range of acceptable values for a selected room acoustic parameter. These recommendations always aim towards achieving optimal acoustics in a room for a specific use. However, not many resources recommend an optimal range for more than one parameter simultaneously, although all room acoustic parameters are connected to a certain degree – if one is changed due to an acoustic intervention, many others will change as well. A good example of a more complex set of recommendations is the Norwegian standard NS 8178 [3] that is focused on performance spaces and gives recommendations on reverberation time for rooms of certain volume, strength and type of music (amplified, weak acoustic and powerful acoustic). Such a complex and multidimensional optimization guideline reveals that there are rooms of certain volume, reverberation time and sound strength that are not particularly suitable as performance spaces at all! Unfortunately, this concept is not easily understood by laymen. Although various charts and diagrams can be helpful when indicating areas of optimum ranges of these parameters, it is hard to believe that such tools will be used by decision makers and investors. However, there are more general recommendations that can be used to indicate important trends in acoustics, such as the one shown in Figure 1.

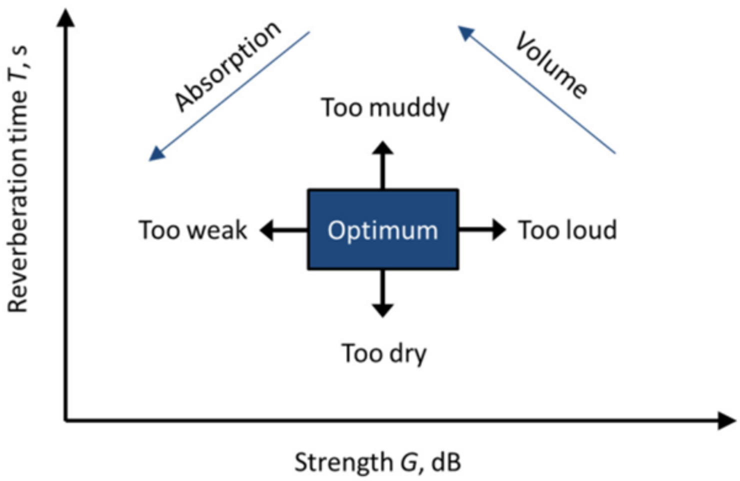

Figure 1: Influence of some acoustic parameters on the reverberation time and strength of rooms, according to Rindel [3].

Since many historical spaces were not built for the purpose they serve nowadays, it cannot be expected that acoustical conditions in these spaces will be appropriate for their current purpose without any adjustments. In some of these spaces it is possible to achieve certain improvement with only minor interventions, whereas others cannot be saved even through thorough reconstruction, as they are fundamentally inappropriate for the events that take place in them. Due to the historical significance of these venues, major interventions that would permanently change their interior are usually not allowed by historians and conservators. The only option that remains is to attempt to improve the acoustic situation through temporary installations that can be easily removed without causing damage.

The usual recommendations about room acoustic parameters are valid for acoustic performances only, without any sound reinforcement system in place. However, the number of performance spaces that require at least occasional, if not regular use of a sound reinforcement system is constantly increasing. Therefore, one must think how the requirements on the acoustics of rooms change to accommodate the presence of a sound reinforcement system, and if certain rooms will be suitable for "electronically assisted" performance without any acoustic redesign. Typically, such rooms serve as venues for contemporary music performances such as pop, rock, jazz or electronic music concerts, etc. A recommendation for the reverberation time for such venues where the sound field generated by the PA system must be controlled by sound absorptive materials, especially in the most critical 125 Hz octave band, can be seen in Figure 2 [4].

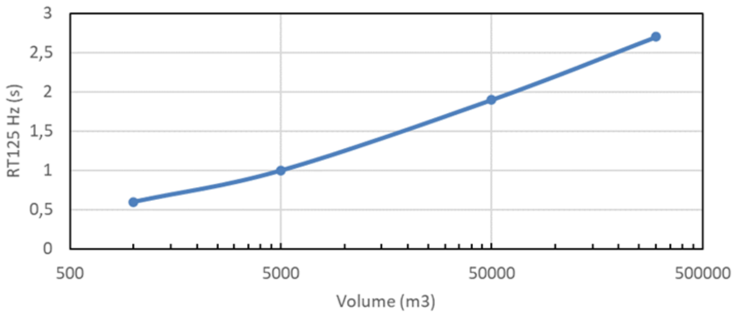

Figure 2: Recommended values of reverberation time in the 125 Hz octave band for performance venues with sound reinforcement, according to Adelman-Larsen [4].

2 Influence of the Covid-19 pandemic on acoustic performances

One of the consequences the worldwide pandemic caused by the SARS-COV-2 virus has on room acoustics of performance spaces is the imposed limitation of the number of visitors that can attend a given event. In some cases, the performances have even been moved from closed to open spaces. Thus, many concert halls, theatres, cinemas and other venues were forced to limit the number of visitors and increase their spacing in the auditorium, and to do the same with performers on stage. Such a change often led to dramatic changes in the acoustics of the room, experienced both by the audience and the performers, particularly if the unused seats were physically removed from the room. A good example can be seen on the left in Figure 3 which shows the concert hall of the Croatian national theatre in the city of Varaždin, built in the usual 19th century shoebox shape, where the main absorption in the hall is coming from the seats and the audience. The right part of Figure 3 shows the same hall during the pandemic, with a significantly reduced number of seats. Consequently, the reverberation time in the hall during musical performances increased to excessively large values, making the hall unsuitable for its usual use, although it was designed for music performances and is well known for its good acoustics.

Figure 3: The concert hall of the Croatian national theatre in Varaždin in its usual setup with performers on the stage and a dense audience seating arrangement (left), and during the Covid-19 pandemic, with a significantly reduced audience (right).

Another example of the influence of Covid-19 pandemics on musical performances can be seen in Figure 4, where musicians had to perform on an improvised stage in front of the Croatian national theatre building in Zagreb. Since this setup had no sound reflectors to direct the sound energy towards the audience, and the venue is surrounded by busy streets, with traffic raising the background noise floor, the only way the concert could be held was with the help of a sound reinforcement system. Although this was an intermittent solution to the current situation, it was far from ideal in the acoustical sense.

Figure 4: An improvised outdoor concert setup for classical music because of the Covid-19 pandemic.

3 Evaluation of historic spaces in the medieval town of Dubrovnik

Historic spaces with great architectural significance are often used as venues for different kinds of events that tend to enrich the cultural life of a modern city. Built in old city centres, often with considerable restrictions on size and shape, they performed different functions throughout the history of a city, none of which necessarily relates to their current use. A case study was made in four public spaces located in the city of Dubrovnik, a UNESCO World Heritage Site. Its old city is a crown jewel of Croatian coast with shining examples of civil and military architecture, but also a centre of rich cultural life that comes to its peak during high season in the summer.

3.1. Investigated venues

The four selected spaces include the atrium of a historic municipal headquarters, now used for classical concerts of soloists and small ensembles (Rector's Palace), the interior of a stone fortress used as a night club with mostly amplified music reproduction (Revelin), a historic classical theatre for various plays (Marin Držić Theatre), and an improvised concert hall for rehearsals and concerts for a small audience of the Dubrovnik symphonic orchestra located in a stone room of unusual proportions (Slanica). The assessment of their acoustical suitability was carried out through measurements of their impulse responses and calculation of the usual objective parameters: reverberation time RT_{60}, early decay time EDT, clarity C_{50} and C_{80}, strength G, lateral fraction LF_E, binaural quality index BQI, speech transmission index STI, initial time delay gap $ITDG$, and specific volume V/N, where N is the number of seats in a typical seating layout in each venue. Several different criteria were applied to determine the extent to which individual spaces were suitable not only for their primary purpose, but also for other potential uses. Based on the results, recommendations were given for possible improvements of acoustic situation in specific spaces, but such improvements are not likely to be implemented due to the strict rules on preservation of historical buildings. Many more details about the venues and the measurements can be found in [5], while this paper will briefly show only the most interesting outcomes of this case study.

3.2. Results and evaluation of acoustic suitability

The summary of measurement results is shown in Table 1 for all four investigated venues. The usability of these spaces regarding their acoustic performance is evaluated by considering only their primary purpose. The values in Table 1 are coloured according to their suitability for a given purpose. The red-coloured values are considered unsuitable, the yellow-coloured ones are borderline suitable, the green-coloured are suitable, and the black-coloured were not considered for a particular space and purpose. The ranges of suitability for all measured parameters are defined in recommendations found in [6–10].

Table 1: Single-number values of relevant parameters obtained at all four locations

Parameter	Rector's Palace	Revelin Fortress	Slanica Concert Hall	Marin Držić Theatre
RT_{60} (s)	3.80	1.34	1.20	0.78
EDT (s)	3.72	1.30	1.20	0.72
C_{50} (dB)	-8.1	-1.3	-1.3	2.1
C_{80} (dB)	-5.5	1.6	1.6	5.9
G_{mid} (dB)	7.0	0.7	5.7	1.6
LF_E	0.20	0.10	0.23	0.12
BQI	0.74	0.63	0.72	0.71
STI	0.36	0.58	0.56	0.68
$ITDG$ (ms)	24.50	2.56	3.74	4.20
V (m^3)	2900	1500	685	1640
N (s)	300	220	170	283
V/N (m^3)	9.7	6.8	4.0	5.8

This visual aid for evaluation of the acoustic suitability of spaces can be helpful for quickly locating parameter values of spaces that are outside their optimal range. In general, one could conclude that the Revelin Fortress might be acoustically best for its purpose, and the Rector's Palace atrium the worst. In reality, the atrium was measured in the unoccupied condition. During concerts, the acoustical situation changes drastically, since the audience introduces a lot of sound absorption. As a result, the concerts held there are usually described in superlatives. On the other hand, the Revelin fortress might serve fine for its current purpose. However, having a night club in an UNESCO-protected medieval town introduces many other administrative and organizational burdens and problems for the municipality and calls for its relocation to a more suitable location.

Another problem of this colour-coded table is that it gives no additional information about the suitability of these venues for other purposes (which was the goal of this project to start with), and there is no information on the "weight" of the presented numbers. In other words, non-professionals cannot judge if a red-coloured value of the clarity bears the same significance as a red-coloured value of reverberation time.

Another attempt was made to present the suitability of these spaces for other purposes. An example for the Revelin fortress is shown in Table 2 with colour-coded suitability marks (red for unsuitable, yellow for borderline suitable and green for suitable). The biggest difference between this way of presenting the suitability of acoustics spaces and the one shown in Table 1 is that here one can visually compare the difference in suitability between various applications of the space. It is obvious that the Revelin fortress has more green-coloured fields for opera than for chamber music, and even less for symphonic music. But this presentation still gives no information on if some of the table fields are more important than others, or if we just have to "count" the good fields to find the best use for a space.

Although far from perfect, the authors believe that this presentation of measured values and their position within

Table 2: The suitability of Revelin Fortress for various purposes based on the mean values of typical acoustic parameters.

Revelin Fortress	RT_{60} (s)	EDT (s)	BQI	G_{mid} (dB)	C_{80} (dB)	$ITDG$ (ms)	V/N (m^3/pers.)	STI
Measured values	1.34	1.30	0.63	0.7	1.6	2.56	6.8	0.58
Symphonical music								
Chamber music								
Opera								
Speech								
Cinema								

the optimal range of acoustical parameters for various uses of a venue represents a simple, yet a somewhat limited way of showing the suitability of a venue for certain types of events. Such displays are invaluable for non-acousticians who have trouble interpreting the numerical values of the acoustical parameters and grasping their meaning for a given venue. Moreover, such a representation can help the local municipality make decisions on possible use of venues, both historic and contemporary ones. The same visual principle was already applied in other recommendations for room acoustic parameters, or even the physical parameters of a room. For example, Figure 5 from [11] shows a coloured display of favourable and unfavourable ratios of room length to its height, as well as the ratios of room width to its height that lead to minimising the influence of strong room modes in a small rectangular room.

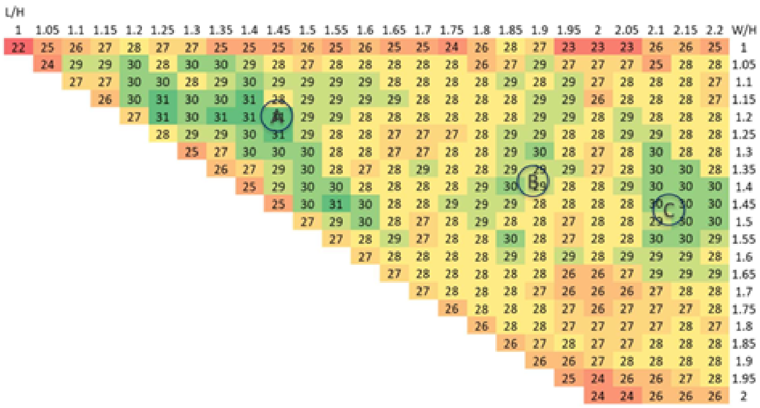

Figure 5: Colour-coded optimization chart for room aspect ratios in order to maximise the number of tones supported by room modes, according to Rindel [11].

4 Acoustic labelling

In this section, the authors tend to establish a simple, easy-to-understand approach to evaluation of suitability of different rooms and halls as venues for various types of events, especially if they were not originally built for a specific purpose. The main goal is to help the non-experts such as managers of such halls understand what their hall is suitable for, and what steps to take, should the evaluation reveal the hall to be unsuitable. To establish the method of evaluation, the authors rely on the German standard DIN 18041:2016 [12]. The earlier version of this standard is in force in the authors' home country of Croatia. The most recent version has not been approved for use at this time due to lack of demand, as stated by the relevant regulatory body. This gives a quite accurate illustration of the present situation in Croatia, with very few experts who use the standard only as a guideline, as room acoustic design is not covered by any laws or regulations. Nevertheless, the authors find this standard to be an invaluable resource in both the design stage for new halls and the evaluation stage for the existing ones.

The approach to evaluation of a hall illustrated in this section relies on three main questions that need answering:

1. Are the room acoustics conditions in the hall appropriate for a given type of event?
2. Is the seating capacity appropriate for the type of event/activity?
3. Will the sound source be loud enough on its own, or will it need the help of a PA system?

To answer the first question, the approach utilizes the requirements on reverberation time for different types of activities as a function of room volume, as given in [12]. The second question can be answered by finding the specific volume, i.e. the volume per seat, and by comparing it with the typical values given in [12]. The third question can be answered knowing the geometry of the room and the properties of the sound source.

The evaluation procedure shall be shown on an example room originally built and used as a classroom. The room volume is 280 m^3, the mid-frequency reverberation time is 1.15 seconds, and the distance from the source to the farthest listener is 10 metres. The room has 72 seats. For this evaluation, it is assumed that the noise level in the room is 45 dBA, that the people in the audience do not suffer from hearing problems, and that the event will involve communication in native language only.

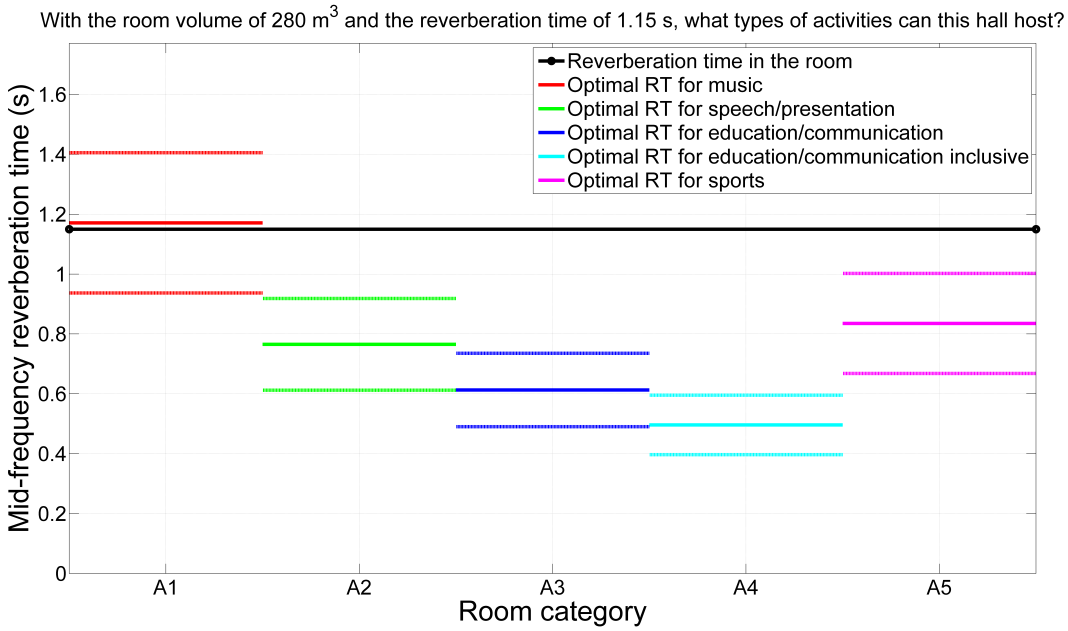

Figure 6: The reverberation time in the example room vs. optimal mid-frequency reverberation times (and tolerance) for different types of activities, calculated for the volume of the example room according to [12]

Figure 6 shows that the reverberation time in the example room makes the room adequate only for music performance, and that the room is too reverberant for any other purpose. If the room is to be used for speech or educational activities, acoustic treatment is needed to shorten the reverberation. To retain the ability of the room as a venue for activities connected with both speech and music, variable acoustics can be implemented up to a point, thus providing the possibility to adjust the reverberation time at least within the tolerance values found for different types of events.

The top chart in Figure 7 shows that the volume of the example room and the current number of seats dictate that the room be used solely for speech-based activities. The bottom chart in Figure 7 offers advice to hall managers and staff by converting the requirements on specific volume shown in the top chart into a range of seating capacity that is adequate for each type of activity. If the hall is to be used for speech, it will support from 47 all the way to 93 listeners, given that there is room for so many people. If the listeners are to enjoy musical performance, their number should be from 23 to 40. For a mix of speech and music, the number of listeners should range from 35 to 47.

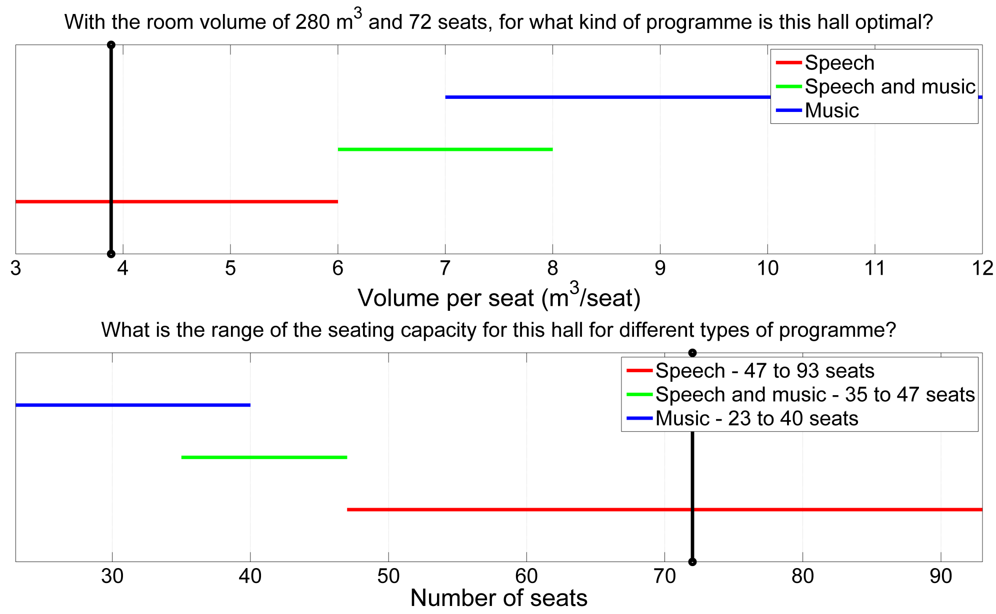

Figure 7: The suitability of the example room with the current number of seats (top), and the ranges of seating capacity for different types of events (bottom), according to [12]

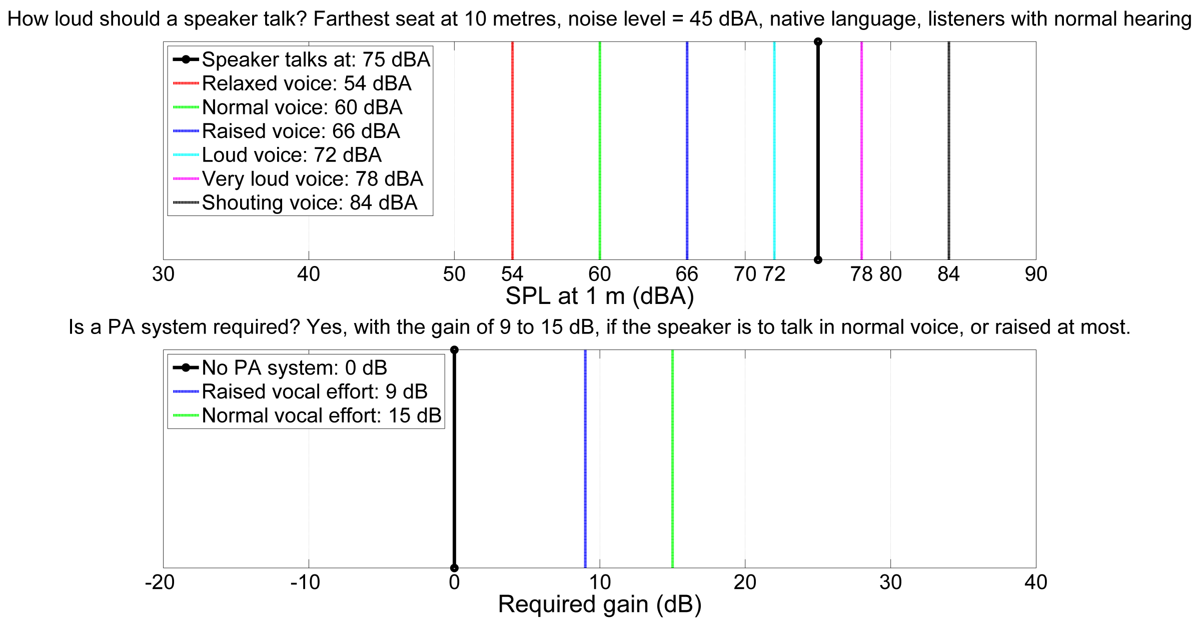

Figure 8: The vocal effort of the speaker without a PA system required to reach even the farthest listener while maintaining the required signal-to-noise ratio (top), and the gain of the PA system (if needed) that allows the speaker to talk in normal/raised voice (bottom).

Finally, Figure 8 shows the vocal effort the speaker will have to put in to reach the listener sitting in the farthest seat of the room. For this evaluation procedure, the authors assume that the level of direct sound of the speaker at the farthest listening position should be 10 dB higher than the level of background noise if native language is used in communication and the listeners have normal hearing (as is the case in this example). For listeners with impaired hearing or for non-native language communication, the difference, i.e. the signal-to-noise ratio should be 20 dB. With the noise level of 45 dBA, the speaker will have to speak at 75 dBA at 1 meter to reach the farthest listener at 10 metres, i.e. they will need to speak loudly or very loudly to accomplish this task, as shown on the top chart in Figure 8. As this effort would either cause fatigue in a rather short time or be impossible for some speakers, a PA system is required, so that the speaker can still accomplish the task while speaking in normal or, at most, raised voice. As the speaker speaking in raised (normal) voice without the PA system would produce 9 (15) dB lower level than needed at the farthest seat, the gain of the PA system needs to be set at these exact values for the PA system to compensate for this shortage. This is shown on the bottom chart in Figure 8.

5 Conclusions

Many researchers in the field of room acoustics already use complex metrics to provide information about the quality of room acoustic design of many types of spaces. They often use a combination of two or more acoustic parameters to form the scientific proof that certain designs will be more efficient than others. This approach, while scientifically sound, is usually very difficult to grasp.

The authors of this paper investigated how the acoustic suitability of spaces used for various applications for which they were not specifically designed and built can be presented to non-acousticians in an easy-to-understand way. The main hypothesis was that the necessity for an acoustic intervention in performance and other spaces can be demonstrated to laymen in a simpler, more intuitive way than by showing numerical values of room acoustical parameters that are beyond the comprehension of non-acousticians.

At the same time, the pandemics of the Covid-19 virus forced many managers of performance spaces to change the usual usage of these spaces by seating capacity and the number of performers, or to use unconventional spaces for acoustic performance events, in compliance with anti-pandemic measures. The experiences gained over the past two years show that these improvisations rarely result in acceptable acoustics. Therefore, an easy way to present these facts to decision makers is required now more than ever.

In this paper, a case study was presented in which the acoustic suitability of several historic spaces in a medieval town was demonstrated to the managing, decision-making bodies. The emphasis was put on the suitability of these spaces for events they do not typically host. The tool used here were easy-to-interpret colour-coded tables. Although this method proved to be quite effective in this particular project, it cannot be universally used since it depends on the known optimal ranges of (too) many specific acoustic parameters, with some of them being appropriate only for specific types of spaces, e.g. for music performance spaces.

To build on this concept, another way of acoustic labelling of the usability of spaces for various applications was presented. The graphical representation was used to check and demonstrate if the reverberation time in a room is appropriate for different types of activities, if the seating capacity is appropriate for the type of event/activity, and, finally, if the sound source in the room will be loud enough on its own or if a PA system should be used. The concept was explained on a prototype room.

The authors believe the presented approach can help acousticians identify the range of events for which a certain room is suitable, according to its design. More importantly, it allows the experts to explain their findings to non-experts such as managers or investors using simple, understandable language, and to explain the basic steps that need to be taken to improve the acoustic conditions in a space if necessary.

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