Do We Still Need Diffuse Field Theory?

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Résumé

Plus de vingt ans après l'article de Murray Hodgson intitulé "When is diffuse field theory applicable?", nous avons rassemblé de plus en plus de preuves selon lesquelles la théorie des champs diffus est essentiellement une chimère. Si nous considérons les deux implications les plus importantes du modèle de champ diffus, à savoir la distribution uniforme du niveau de pression acoustique et l'invariance du temps de réverbération, il est assez facile de dire que de telles conditions ne sont pratiquement jamais retrouvées, sur la base de mesures réelles dans plusieurs espaces différents. La diffusion sonore idéale nécessite des conditions ergodiques et de mixage, qui ne se produisent pas nécessairement, notamment lorsque l'absorption acoustique est répartie de manière inégale ou lorsque les pièces ne sont pas proportionnées. Ainsi, apparemment, la théorie des champs diffus pourrait être écartée au profit d'approches plus précises capables de prendre en compte la nature spécifique de chaque espace. De nos jours, nous disposons de plusieurs instruments allant des nombreuses variations de l'algorithme de lancer de rayons à la solution numérique de l'équation d'onde. Cependant, ces méthodes reposent sur la mesure ou l'estimation d'autres coefficients qui, s'ils ne sont pas correctement calculés, peuvent introduire des inexactitudes encore plus grandes. Une analyse critique est présentée ici, principalement basée sur l'expérience de recherche de l'auteur, montrant que la théorie des champs diffus représente toujours un moyen important de comprendre la propagation du son dans des espaces clos.

Mots clefs: champ sonore diffus, modèles de prédiction, Murray Hodgson

Abstract

More than twenty years after Murray Hodgson's "When is diffuse field theory applicable?" paper we have gathered more and more evidence that diffuse field theory is mostly a chimera. If we consider the two most important implications of the diffuse field model, i.e. uniform distribution of sound pressure level and reverberation time invariance, it is quite easy to say that such conditions are hardly ever found, based on actual measurements in a number of different spaces. Ideal sound diffusion requires ergodic and mixing conditions, which do not necessarily occur, particularly when sound absorption is unevenly distributed or rooms are not proportionate. Thus, apparently, diffuse field theory might be dismissed in favour of more accurate approaches capable of taking into account the specific nature of each space. Nowadays we have several instruments spanning from the many variations of the ray-tracing algorithm to the numerical solution of the wave equation. However, such methods rely on the measurement or estimation of other coefficients that, if not properly made, may introduce even greater inaccuracies. A critical analysis is presented here, mostly based on the author's research experience, showing that diffuse field theory still represents an important way to understand sound propagation in enclosed spaces.

Keywords: diffuse sound field, prediction models, Murray Hodgson

1 Introduction

As a young researcher in acoustics, needing advice from those who had already mastered the discipline, it was an obvious choice to rely on my advisors and tutors, who were there in person, but, in addition, a handful of "sacred texts" were constantly on the desk, ready to be consulted for a prompt reply (it was quite uncommon to "google" everything at the time). Among that pile of books, there were also some papers, and Murray Hodgson's "When is diffuse field theory applicable?" [1] was one of the most crumpled (and covered in notes) due to frequent use. In fact, in its concise and schematic clarity, the paper always provided guidance as to which classical formula for diffuse field had to be used or which were the conditions that

allowed the safe use of either one formula or another in order to predict reverberation time or sound pressure level. The paper relied on the in depth study Hodgson had conducted on this topic, also involving the role of scattering elements in rooms [2,3], and the reliability of the Eyring and Sabine equations when non-low absorption conditions were met [4], as well as discussing them in the perspective of "engineering accuracy" which he assumed to be ±2 dB for sound pressure level, and ±10% for reverberation time. In times in which the only alternative to classical formulas were the costly and not yet fast or friendly ray tracing tools, such guidance was of the greatest importance in order to understand when diffuse field theory could be applied.

When discussing whether real rooms might be considered to fulfill wide ranging requirements, Hodgson stated that "Generally, sound-decay curves are quite linear, and diffuse-field reverberation-time prediction is quite accurate in most real rooms. Consequently, average surface

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absorption coefficients derived from measured room reverberation times using diffuse-field theory have considerable applicability. However, diffuse-field steady-state sound pressure level prediction is seldom accurate in real rooms and can, in fact, be highly inaccurate."[1] The fact that sound pressure level (and other more sensitive energy-based parameters) were not responding to the diffuse field theory predictions had previously been discussed (and brilliantly resolved) by Barron and Lee [5] with reference to auditoria. They assumed that total sound was made up of direct sound and a linearly decaying reflected component (depending on source-receiver distance). Apparently, only the simplest rooms, with very little sound absorption, behaved as expected.

According to the theory, propagation of sound inside an enclosure can be described as a twofold process. First a deterministic process is followed, since the single or multiple contributions (within a limited order) stemming from reflections on room boundaries can be easily spotted. Secondly, due to the increasing number of contributions, the process becomes purely stochastic. In particular, these latter conditions are satisfied when the room is ergodic and mixing [6]. The first term refers to the sound trajectories, where the time spent close to a point is the same for all points in the enclosure. The second term implies that two trajectories initially close to each other shall have a vanishing correlation as time goes to infinity (in other words there should be no memory of the initial state after a certain time). When both conditions are satisfied the result is an ideally diffuse sound field, meaning that the sound energy is uniformly distributed in the space. It should be emphasized that a mixing room is a necessary, but not sufficient, condition to obtain diffusion. In fact, non-uniform surface absorption, or disproportionate rooms, may significantly compromise the diffuseness of a sound field.

Therefore, it seems that the sound field in an enclosed room is, more often than desired, far from being ideally diffuse. Nonetheless, formulas based on diffuse field theory have been used for a long time. At the end of his paper [1], Hodgson concluded that "practitioners using diffuse-field theory should be aware that the assumption of a diffuse sound field may seriously limit the accuracy of prediction, particularly of steady-state sound pressure level." Then he recommended: "Models, such as the method of images and ray tracing, which are accurate in the case of non-diffuse sound fields, are available."

Nowadays we have even more powerful instruments to model the sound field in a room. They span from the many variations of geometrical acoustic (GA) methods [7], including ray-tracing, cone-tracing, beam-tracing, image source methods, radiosity, to diffusion equations [8,9], up to the numerical solutions of the wave equation (based on finite elements, boundary elements, finite difference time domain, etc.) [10]. All these methods rely on the proper description of the surface properties, which is not just limited to diffuse field absorption coefficients and scattering coefficients, but may now include angle-dependent behavior and complex impedance. However, even limiting the choice to absorption coefficients, which are certainly (and

dangerously) the easiest values to find, there are several issues which undermine the quality and the reliability of the final result. The first aspect is that Sabine's absorption coefficients, which suffer from large measurement uncertainties depending on the test room [11], differ from diffuse field absorption coefficients to be used in geometrical acoustic tools. Solutions to overcome this problem have been proposed and will be discussed in detail later, but they are mostly circumscribed to research environments. Similarly, normal incidence absorption coefficients measured in a standing wave tube cannot be used "as is" in geometrical acoustic tools as this would normally underestimate the absorption [12]. Thus, a practitioner aiming to use one of the many widely available commercial tools based on geometrical acoustics, should be equally aware of the "traps" along the way.

Among the emerging methods (diffusion equation, finite-difference-time-domain, etc.) the treatment of the boundary surfaces is not a straightforward issue. When using diffusion methods, proper adaptation of absorption coefficients is needed [13]. For wave-based methods things get even more complex because of several factors, including the difficulty to model frequency dependent absorption, the surface discretization (staircasing), the need to know angle-dependent impedances rather than just diffuse field absorption coefficients, just to mention the most critical. Nevertheless, convenient solutions have been provided to address most of these issues [14], so the spread of such methods is to be expected. However, for the purpose of comparison with diffuse field theory, as wave-based methods are typically effective in a frequency range where the diffuse-field theory cannot be applied at all, they will not be considered in the following presentation.

In the subsequent sections, the paper discusses in more detail the problems related to the application of the diffuse field theory in real rooms, both in terms of energy distribution and reverberation time, mostly taking advantage of the author's own experience. Then, the current alternatives to the theory are also outlined, discussing some accuracy issues pertaining to input parameters and calculation algorithms. Finally, an attempt is made to respond to the initial question.

2 Diffuse field theory and real rooms

2.1 Sound energy distribution

As anticipated, one of the most evident deviations from diffuse field theory predictions is the non-uniform distribution of acoustic energy in enclosed spaces. When the relative sound pressure level is considered (i.e. the sound strength G) the theory states that [5]:

$$G(r) = L(r) - L_{10} = 10\,log(100/r^2 + 31200\,T/V) \quad (1)$$

Where T is the reverberation time, V is the room volume, and r is the source-receiver distance. So, according to the formula, when the distance from the source is greater than the critical distance, G is reduced to $44.9+10log(T/V)$. Taking advantage of a large set of measurements carried out

by the author in churches [15] it was possible to show that, when considering average values, the agreement between theory and experimental values was good (Figure 1).

Gth=44.9-10 Log(V/T30)

G = 45.2 -10.3 Log(V/T30)
R2 = 0.943
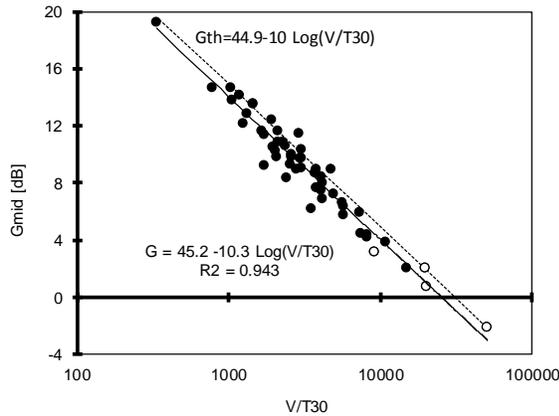
Figure 1: Plot of the of sound strength (averaged at 500 and 1000 kHz) as a function of the V/T30 ratio.

However, this apparently reassuring observation had to be revised after checking the actual dependence as a function of distance. In this case the results showed a much-varied condition (Figure 2). In all the cases, and particularly for the largest spaces, such as the church of the Holy name of Jesus in Rome [16] (Fig. 2a) and St. Peter's Basilica in Rome (Fig. 2b), the level kept on decreasing well beyond the critical distance. In the first case, the overall room volume was approximately 40000 m^3, and in the second it was about 500000 m^3. Both churches had quite long naves (but St. Peters' was twice as long as the first one) and large transepts with central domes. Thus, the observed behavior was likely to depend on a subtraction of acoustic energy from such subspaces, which consequently weakened the early reflections, particularly at the farthest receivers. The analysis of the energy decay plots clearly confirmed such behavior.

According to measurements carried out by the author in theatres [18], smaller and more compact than churches, the variations were less dramatic than in the previous cases, but they were present nonetheless. In such cases some of the farthest receivers were located in boxes or close to curved walls around the stalls, clearly contributing to provide strong early reflection.
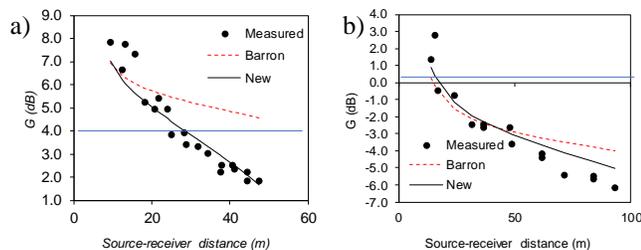
Figure 2: Plot of the distribution of sound strength (averaged at 500 and 1000 kHz) as a function of distance in: a) Church of "Gesù" in Rome, b) St. Peter's basilica in Rome. The blue line represents the diffuse field value neglecting the direct sound contribution

Therefore, the reduced rate of variation was not a matter of better compliance to diffuse field theory.

In all the cases a comparison with semi-empirical models like Barron and Lee [5] and its variation specifically adapted by the author to churches [19], showed that the first model fitted data measured in theatres very well, while the accuracy tended to decrease in churches (particularly at the furthest points). The second model managed to better match the observed values by reshaping the energy decay curve as the superposition of two exponentially decaying processes (one affecting the early reflections and one representing the ideal diffuse field). In addition, it proved also to be suitable for other spaces, such as churches acoustically treated as auditoria, if the input parameters were properly chosen [20]. Whatever the model used to "revise" the theory, the limitations of the "diffuse field" model were mostly located in the early part of the decay, suggesting that the late part of the decay behaved as expected, at least when rooms were proportionate and mixing.

The empirical observation that any decay process could be schematized as the combination of multiple exponential decays suggested that, as already demonstrated by Anderson and Bratos-Anderson [21] for St. Paul's Cathedral in London, the acoustics of complex spaces might be described as the sound propagation in a system of coupled volumes. According to this approach the diffuse field theory still retains its validity, but it is applied to a system of subspaces mutually connected. Therefore, the variation in the early energy part results from the acoustic energy flow from one volume to the others, depending on coupling apertures and sub-volumes. As explained in detail in Ref. 17, the resulting energy balance equation is:

$$V_i(dE_i/dt) = -cA_iE_i/4 + \sum_j cS_{ij}(E_j - E_i)/4 \qquad (2)$$

where c is the sound speed, E_i denotes the average sound energy density in the i-th subspace, V_i is the volume of the i-th subspace and A_i is the equivalent absorption area of the i-th subspace calculated as $S_i\bar{\alpha}_i + 4mV_i$, where S_i and $\bar{\alpha}_i$ are respectively the total surface area and the geometrically averaged absorption coefficient of the i-th subspace, and $4mV_i$ is the propagation loss due to air. The coupling area between subspace i and adjacent subspace j is denoted $S_{i,j}$.

Application of this model, as refined by Summers *et al.* [22], was successfully tested by the author in Roman basilicas [15,17], while Chu and Mak [23] also proposed an improvement based on the use of a delayed coupled volume model which was tested in two Chinese churches. The application to St. Peters' Basilica (Figure 3), as well as to other Roman basilicas, proved capable of accounting not only for sound level variations but also for other energy-based parameters like center time, as well as for early decay time. Thus, after all, a proper application of diffuse field theory managed to explain the acoustic behavior of very complex spaces.

Uneven level distribution is also a typical problem in many spaces in which the reverberation time shows no significant spatial variation. However, there are a number of

cases in which this parameter also needs to be carefully taken into account.
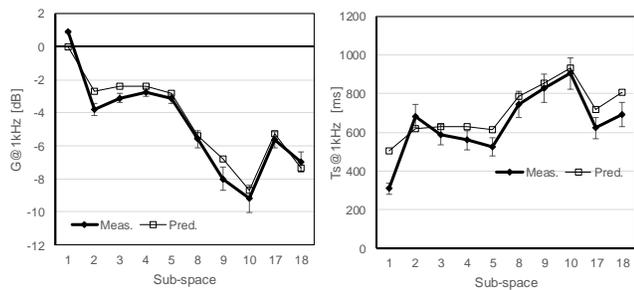
Figure 3: Plot of the distribution of sound strength and center time (at 1 kHz octave band) in St. Peter's Basilica in Rome, measured and predicted using a statistical acoustic model of coupled volumes.

2.2   Reverberation time related issues

When dealing with reverberation time, it is common experience, as Hodgson had anticipated [1], that "generally, sound-decay curves are quite linear, and diffuse-field reverberation-time prediction is quite accurate in most real rooms". In fact, most of the effects that have been discussed above affect the early part of the decay and, consequently, have a lesser influence on the late decay. So, as reverberation time is always calculated by excluding the first 5 dB of the decay, the adverse effects are certainly limited [24]. However, it is not unusual to find exceptions due to particularly evident influences of early reflections (e.g. in very large spaces where even T20 or T30 may show dependence on source receiver distance), or due to coupled volume phenomena. In both cases, the use of Bayesian estimation [25] may reliably contribute to identifying the different components of the decay process. The real problems arise when it is the late part of the decay to show large variations, which normally takes place when the fundamental assumptions of the theory are, in some way, not satisfied. Thus, disproportionate rooms, and non-uniform distribution of absorption are the typical causes for such behavior, but the appearance of modal effects may equally contribute to abnormal distribution of reverberation times, particularly in smaller rooms.

A singular example of such odd behavior which was investigated by the author and colleagues is the crypt of the Cathedral of Cadiz [26], where the reverberation time measured in the "rotunda" dramatically changed by simply moving the source along the axis. Without going too deeply into the details of the complex phenomena occurring in this space, the problem could be summarized by stating that the shape of the space clearly contributed to originating flutter echoes between the floor and the dome, which became more evident when the source position moved off the border. The flutter echoes involved all the receivers in the rotunda, as shown by the "staircase effect" in the decay curve in Figure 4. A detailed analysis demonstrated that they were caused by a complex 3D path, and resulted in a much longer reverberation time. The same decay process also appeared,

although with a reduced magnitude, in the side chapels as a consequence of the weak coupling between them.
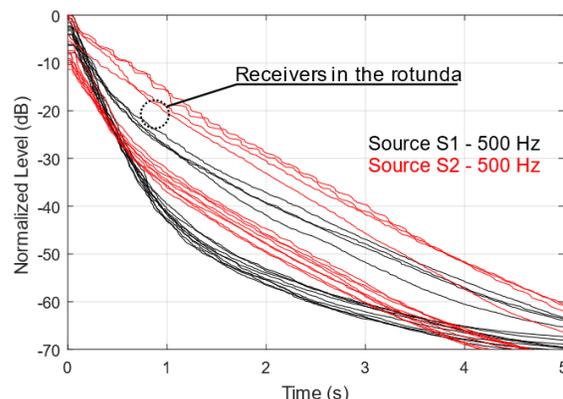
Figure 4: Normalized backward integrated decay curves in the 500 Hz octave band, as a function of source and receiver position. Normalization is obtained in each case by taking the receiver with the highest relative level as a reference.

Non-uniform distribution of reverberation times (or strong dependence on the source position) may become real problems if the room is used to test sound absorption coefficients, as this may cause different results depending on the measurement set-up, or on the particular set of sources and receivers chosen for the measurements. From this point of view ISO standard 354:2003 [27] poses no limitations to large T30 variances. In fact, the only qualification test that the room must pass refers to diffuser installation which must ensure that the measured absorption coefficient is maximized. Conversely, ASTM C423-17 [28] requires the relative values of the variation of decay rates with microphone position (to be moved in at least five positions) to be smaller than a maximum limit, when the room is empty. The relative variation is expressed as the ratio of the standard deviation between decay rate measurements (s_M) and their mean value (d_M).

To give an idea of the sensitivity to change of any of the possible variables, assuming ASTM limits as a reference, a set of measurements were carried out by the author in a 200 m^3 reverberant room complying with ISO standard 354, with six diffusers (covering an overall surface of 10.2 m^2) installed to comply with Annex A requirements. Figure 5 shows the set of measured reverberation times and the corresponding relative variations under normal use, with sources at the corners (Fig. 5a), with source and receivers moved to different positions and some diffusers removed (Fig. 5b), and with the room filled with a 10.8 m^2 sample of 2 cm polyester fiber mat (Fig. 5c).

In the first case, in which both source positions were in the corners and the receivers were kept at 1 m from walls but along the peripheral area of the room, the standard variations were within the limits in nearly all the frequency bands (with the only exception at 200 Hz, where the limit was slightly exceeded). In the second case, one of the sources was moved far from the corner and one of the receivers was moved towards the center of the room,

causing significant variations, particularly in the low frequency range. The large variation of about 6 s depended on the significant differences appearing in measured reverberation times when the source was in the corner and receiver in the center (resulting in the lowest measured values), and the combination with source far from walls and receivers at the opposite position of the room (resulting in the longest measured values). Finally, it was interesting to observe (Fig. 5c) what happened when the room was filled with a large sample of a material to be tested (2 cm thick fiber mat). This test was not requested by any standard but showed the dramatic variations also appearing at medium-high frequencies as a consequence of a clear violation of the diffuse field conditions. Similar results were obtained for different materials.
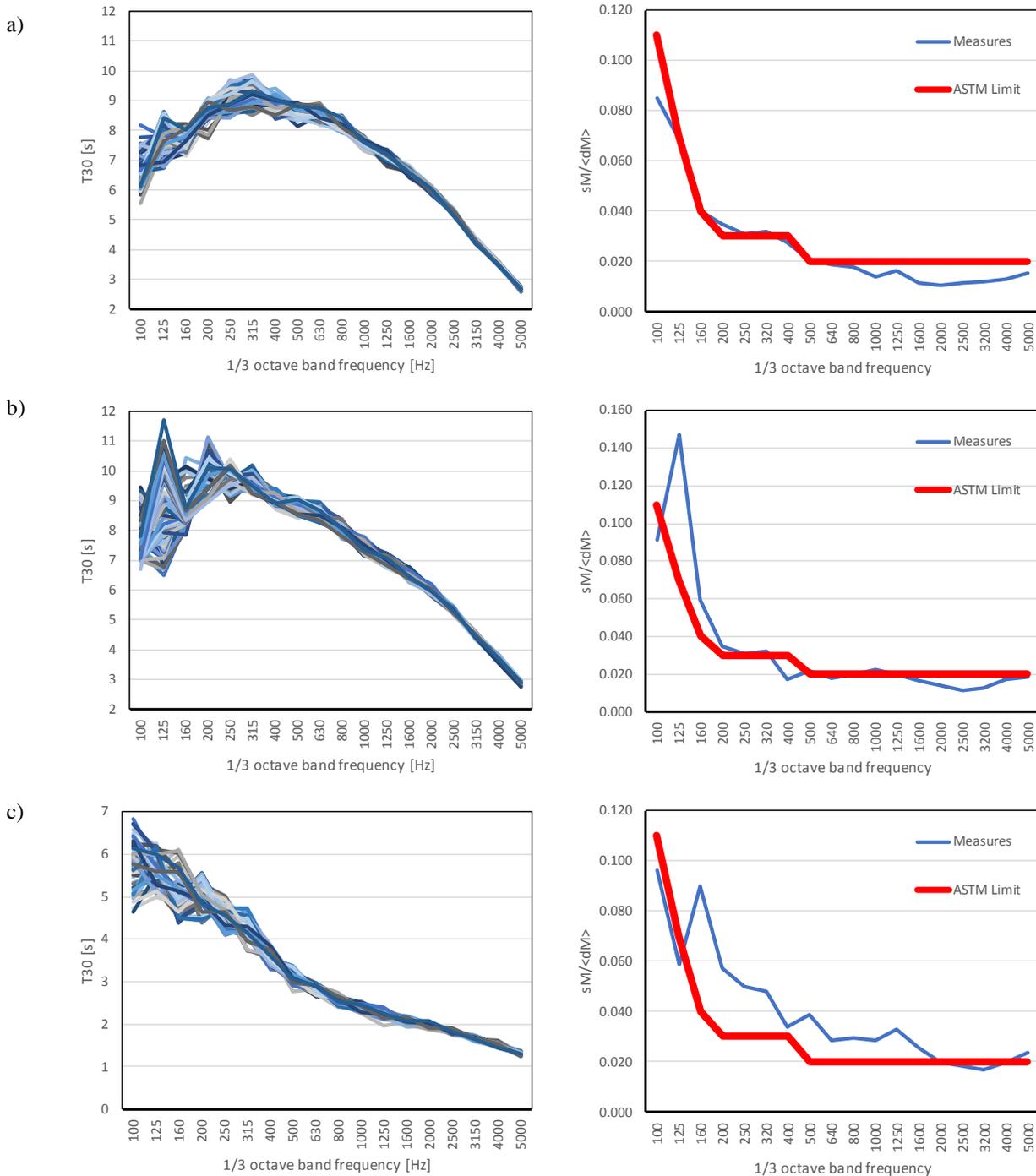
Figure 5. Plot of measured reverberation times as a function of frequency and relative variations of decay rate with microphone position compared with ASTM C423 limits. a) Reverberant chamber with sources in the corners; b) Reverberant chamber with one source in the corner and one far from the walls; c) Reverberant chamber with sources in the corner and a 10.8 m^2 absorbing sample.

The above observations showed that reverberation time varied more than expected, particularly in the lower frequencies, but this does not imply that the resulting absorption coefficients should be less accurate. In fact, a comparison of the absorption coefficients measured using both of the previously mentioned configurations (Figure 6) showed very small variations in the medium and low frequency range (where the standard requirements were not met), while some slightly greater differences appeared at the highest frequencies (with nonetheless negligible variations, never exceeding 7%). Thus, the relative variation of the reverberation time in the room was apparently not, by itself, a measure of the reliability of a measurement. The differences in the high frequency range were probably due to the removal of some of the diffusers, which had a limited effect on the s_M/d_M parameter when the room was empty, but made a difference with the sample in place. Thus, in the presence of a long reverberation time, increasing the number of measurement positions might be a safer choice than just choosing a set of combinations that minimize the change.

Nonetheless, it is a matter of fact that changes in the room configuration and, more obviously, changes within the room, may induce significant variations in measured absorption coefficients [29]. The shape of the room and the position (and type) of the diffusers may play a major role in directing sound reflections towards the sample under test. If diffusers (or dampers) are not properly located, persistent reflection paths may move above the sample with limited interactions with it (at least at high frequencies), resulting in a lower absorption. Overall, observed variations can be quite large, with standard deviations which may exceed ±0.1 in many cases, particularly if highly absorbing samples are tested. Such inaccuracies in absorption coefficient measurements also pose serious problems when using numerical tools but this will be discussed in more detail in the next section.
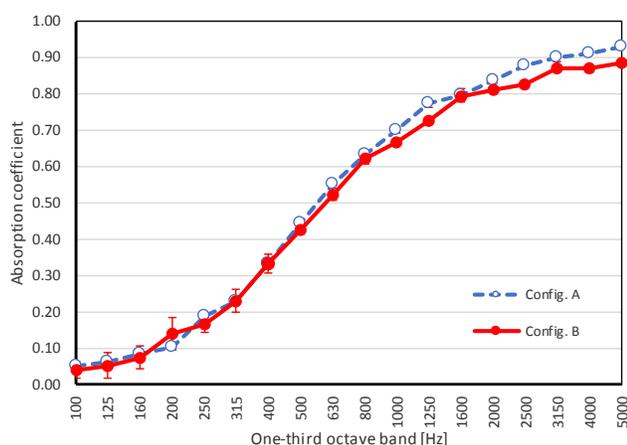
Figure 6. Plot of absorption coefficients of a 2 cm polyester mat under the two configurations analyzed in Fig. 5

3 Computational methods

It is clear from the previous discussion that the cases in which diffuse field theory is strictly valid are very limited

and, consequently, the use of classical formulas to predict acoustical parameters or derive, indirectly, the absorption coefficients, may lead to more or less significant inaccuracies. Therefore, as Hodgson suggested in his 1996 paper, other methods based on geometrical acoustics should be considered as alternatives. However, since then GA tools have become so widespread that they are now available both as specialized acoustic tools but also as plugins of 3D modeling tools, and are therefore accessible to a much wider (and not sufficiently aware) audience. Meanwhile, increased computation power made several alternatives available, including the use of diffusion equation which was largely studied by Hodgson himself, as well as solutions of the wave equation based on finite elements, boundary elements, or finite-difference-time-domain (FDTD) approaches, which now allow to complement GA methods in the low frequency range. Anyway, at the moment the latter are still circumscribed to a more selected audience of researchers, which should, in principle, imply that they are used with criterion.

The description of the available computational methods goes well beyond the scope of this paper and has been addressed by several scientific papers and reviews [7,10]. However, in order to understand if such tools may be reliably used by the acoustic practitioner it is important to point out the main causes of uncertainties in acoustic modelling. Vorländer[30] in his comprehensive analysis of the problem subdivided the uncertainties in two groups: systematic and stochastic. Systematic uncertainties include those related to the level of detail of the geometric model, to the presence of curved surfaces, to the effect of diffraction, and, finally, to spherical wave impedance. Stochastic uncertainties are related to the number of rays, and to the choice of absorption and scattering coefficients. The main conclusion of the paper is that by using absorption coefficients measured according to ISO 354 [27] (i.e. those typically listed in textbooks and in the same datasets provided by commercial tools), it is impossible to obtain simulated results with an uncertainty below one just noticeable difference. In fact, by propagating uncertainty it is shown that the uncertainty of T30 follows that of the absorption coefficients pertaining to materials with the highest absorption, which may well be characterized by variations of ±0.1 (and things may get worse if seats and audience are considered).

However, even though, ideally, one should be able to get a perfectly suitable acoustic model of a space by simply using literature data, anyone ever involved in the acoustic simulation of an existing space knows that in order to get the best possible agreement between measurements and predictions a calibration step is needed. Calibration typically consists in changing absorption coefficient values until a better match is obtained between measured and predicted reverberation times (with the maximum error being assumed as 5%, or one just noticeable difference).This is one of the most "subjective" (and hence questionable) tasks which may be carried out and, consequently, many authors tried to propose more objective approaches [31], or possibly use completely automated systems based on least-mean-squares

optimization [32]. However, if performed under the right conditions, that is when there is one surface with markedly different characteristics or, like in a reverberant chamber test, a sample that is added to the space, this procedure may provide very interesting results with the advantage of returning absorption coefficients which can reliably used. This procedure was first proposed by Benedetto and Spagnolo [33] and subsequently applied by Summers [34] to characterize seat blocks, and by the author and colleagues [35, 36], to define absorption of seats, audiences, and tapestries in churches.

The main advantage of this method is that, if properly carried out, it may account for the surface behavior as a whole (thus including both absorption and scattering), with reference to the chosen level of detail of the modelled surface which, in this case may be relatively low. All the effects due to irregular shape will simply be accounted by absorption and scattering coefficients. This might contribute to significantly remove, or limit, the uncertainties due to the geometric model discretization.

The level of detail of the geometric model has been a long debated issue. In fact, a high level of detail in the model certainly lengthens computation time because of the need of a proportionally higher number of rays in order to hit the smallest surfaces. In addition, evidences supporting an improved reliability of the acoustic results are still not convincing. So, it is common practice to avoid including smaller details (relative to the scale of the room) to find a balance between geometrical accuracy and computation time. Replacing complex and detailed surfaces by means of simplified blocks implies that their absorption and scattering coefficients need to properly take into account the original features of the surface. The computation will consequently be much faster, but the adaptation of the coefficients, if not carried out according to one of the objective procedures described above, needs an experienced user to avoid problems.

As an example, it can be instructive to recall the case of St. Peter's Basilica in Rome [17], which, despite its volume of 500000 m^3 was modelled by the author by using only 1500 planes. The absorption coefficients of the surfaces were assigned, where possible, by comparison with other buildings where those surfaces where found (and their presence directly influenced the reverberation time), then by iteratively changing the coefficient for the largest surfaces (about 40% of the total) largely covered by decorations. Although made of marble, the absorption coefficients varied between 0.04 at low frequencies and 0.08 at high frequencies. Specific tests with scaled down models of similar decorations proved that, compared to the flat version of the same surface, the presence of the decorations increased the absorption from 50% to 110%. Scattering coefficients were accordingly changed as a function of the decoration dimension compared to the wavelength. The resulting accuracy in parameters prediction was very good, with point by point differences well within the just-noticeable-difference in nearly all the cases (Figure 7).

In the previous discussion absorption and scattering were considered together, but it is worth specifying that if absorption is affected by measurement uncertainties and, particularly for existing spaces, by the problem of finding "equivalent" surfaces, scattering coefficients present even bigger problems. In fact, tables with measured data are still too few [37, 38], and many surface treatments which are sold as "diffusers" do not even have scattering data although a standard procedure has been defined since several years [39]. There are some computational tools which allow calculation of the scattering coefficients based on the specific design, but they work in 2D and for mostly repetitive patterns. In addition, GA tools often treat scattering differently (some by assigning a reference value and deriving the relevant octave band values, some by directly assigning them in octave bands). So, the risk is that an inexperienced user may neglect this coefficient, or just assume default values, but this may lead to significant variations in the final results.
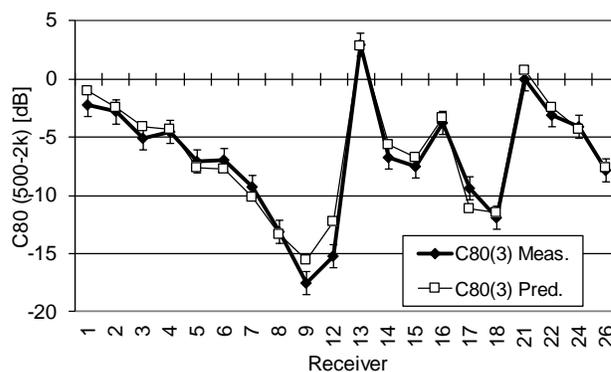
Figure 7: Plot of multi octave average of clarity (C80) as a function of receiver positions measured and predicted (using GA model) in St. Peter's basilica in Rome

4   Conclusions

At the end of this brief digression on the state of the "diffuse field theory" it is clear that, despite the many limitations and boundary conditions that need to be satisfied in order to strictly apply the theory, we cannot definitely dump it as it still proves to be robust enough to offer useful predictions without significant effort. In addition, despite the widespread availability of alternative tools based on geometrical acoustics and other computational models, without a clear understanding of the theory and of the fact that models rely on measurements which depend on the theory, obtainable results may be characterized by uncertainties which remain quite high for the time being. Actually, any good acoustician will be likely to use both theory and computational tools, to find her/his way through acoustical problems. Hence, when one considers the acoustics of a space, used for listening or evaluating the absorption coefficient of materials, the answers Murray Hodgson gave to the question "When is diffuse field theory applicable?" remain a safe guide.

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