The Sound of a Monumental Architecture

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Résumé

Le présent ouvrage se veut un commentaire scientifique sur la performance sonore “SynAsTex Korrektur” de l'artiste allemand Florian Hecker. Le choix du lieu de la représentation est tombé sur l'atrium rationaliste de l'École des Ingénieurs de l'Université de Bologne, qui fait partie d'un bâtiment historique datant des années 1930. L'étude tente de répondre à certaines questions. Quel rôle l'acoustique d'un atrium monumental - constitué de marbre et de surfaces réfléchissantes - peut-elle jouer lors de performance électronique? Dans quelle mesure la présence du public debout peut-elle influencer l'acoustique de la salle? Quelles sont les particularités de la répartition de l'énergie sonore dans ce type de champ sonore fortement non diffus? L'évaluation de l'état acoustique a été réalisée par des simulations acoustiques, en utilisant une approche basée sur les rayons sonores.

Mots clefs: atria acoustique, GA simulation, performance électroacoustique, champ sonore non diffus

Abstract

The present work is intended to be a scientific commentary on the “SynAsTex Korrektur” sound performance by the German artist Florian Hecker. The choice of the venue for the performance fell on the rationalist atrium of the School of Engineering of the University of Bologna, which is part of a historical building dating back to the 1930s. The study tries to answer some questions. Which role can be played by the acoustics of a monumental atrium - which is made by marble and reflective surfaces - in an electronic performance? How much may the presence of the standing audience influence the room acoustics? Which are the peculiarities of the sound energy distribution in this kind of strongly non-diffuse sound field? The assessment of the acoustic condition was carried out through acoustic simulations, employing a ray-based approach.

Keywords: atria acoustics, GA simulation, electroacoustic performance, non-diffuse sound field

1. Introduction

Thermal performances and lighting strategies of atria [1] are well treated in the scientific literature [2, 3], but only in recent years scholars also focused on the acoustics of such spaces [4–9]. In general, atria have high reverberation times, due to the low sound absorption of the surfaces. The geometry and the materials can increase the scattered sound field, enhancing the listener envelopment [10]. The coupling between large and small volumes changes the sound energy distribution [11] and influences the frequency response (considering the different situations, a similar effect is due to the orchestra pit in opera houses [12]). In the specific case of atria, the comfort of visitors was studied by [13] and the perception of background music in [14].

Such kind of places can be intentionally used as music spaces [15]. The large reverberation and the coupling effects may enhance some music genres, as large worship spaces do for the Gregorian chant [16]. The perception of the music in reverberant field is discussed either by acoustical [17, 18] or phenomenological approaches [19, 20]. Regarding the latter one, the interest of some scholars was focused on the electroacoustic performance [21].

Since the 1970s, concrete and electronic music have employed multichannel reproduction through multiple sound sources. It should be noted that with this approach the single loudspeaker is considered as a single part of a composition.

According to the aesthetic intention of the composer/performer, the loudspeaker own-directivities are used to enlarge the apparent source width or to enhance the listener envelopment. In the early approaches to this technique, the sound sources were placed as the orchestra instruments. This way, the listening experience was similar to the one you may have in an opera house, with early reflections and late reverberation. This is the case of the so-called *Acousmonium,* which was discussed in [22]. In other cases, the composer chose to place several loudspeakers in a reverberant space, enhancing the spatial experience of the listener [23–27]. The case under study belongs to the latter situation.

The occasion of “SynAsTex Korrektur” sound performance, hosted in the atrium of a rationalist building, led the authors to develop a virtual model of the space. The simulation considers the multi-channel configuration of the electroacoustic performance and its relationship with the audience. Moreover, the simulation helps understanding how the presence of listeners influences the acoustic behaviour of the sound field. Finally, the model may help the organizers of performances in large reverberant spaces to consider the sound experience of the listeners.

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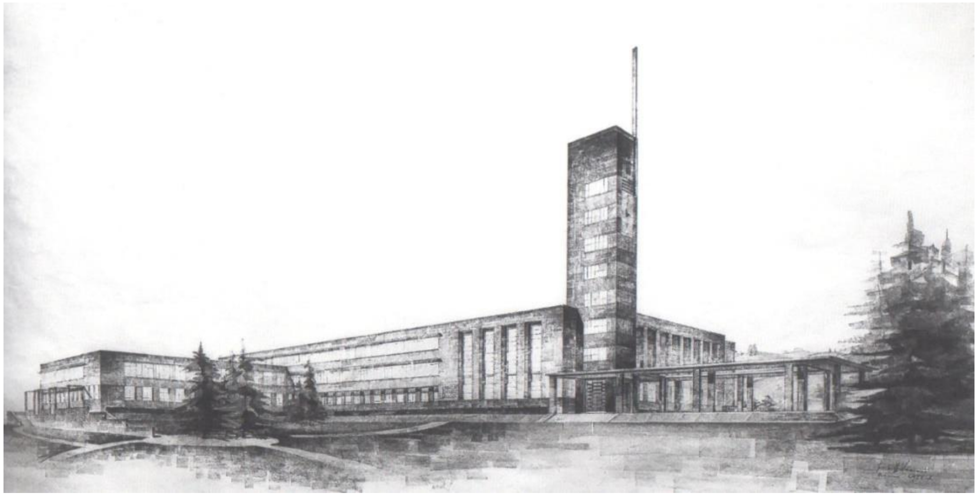

Figure 1: Sketch of the building done by architect Giuseppe Vaccaro (1896–1970). Credits image: Maristella Casciato, Giuliano Gresleri, eds. Giuseppe Vaccaro. Architetture per Bologna [28].

Figure 2: Inside views of the atrium of School of Engineering during the SynAsTex Korrektur performance. Photo by: Luca Ghedini, courtesy Xing. Credits photo: F. Hecker, SynAsTex Korrektur sound performance (première) curated by Xing, in the ART CITY event (ARTE FIERA), Bologna 2019, 31/01/2019 - 01//02/2019, University of Bologna, School of Engineering.

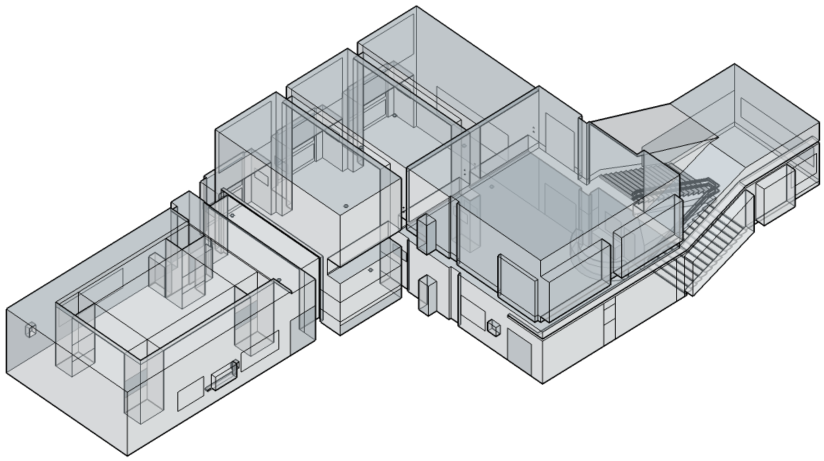

Figure 3: View of the virtual 3D model created with SketchUp software for acoustic simulations.

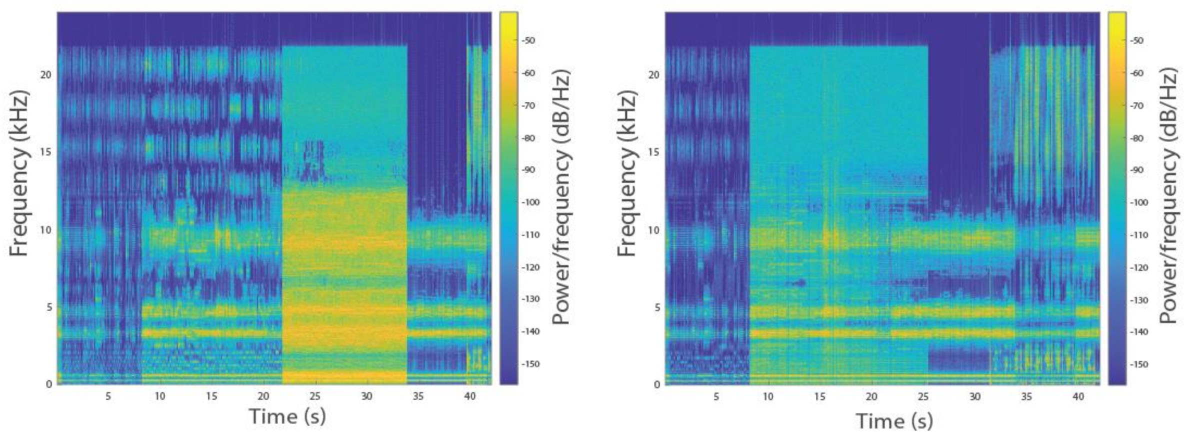

Figure 4: Spectrograms (4192 points at 48 kHz, Overlap 10%) of extract from music signals of Hecker's composition. Two out of nine channels are shown.

2. Simulation strategy

The building under study was designed by Giuseppe Vaccaro (1896-1970) to host the "new" School of Engineering in Bologna (see fig. 1). The construction was completed in 1935 and it is considered one of the most remarkable example of rationalist architecture in Italy [28–31]. Vaccaro's work was characterised by a broad use of concrete, marble, and wide windows with iron frame. The atrium shows the original configuration, including materials, window frames and furniture. The false ceiling was renovated in the early 2000s for safety reasons.

The "SynAsTex Korrektur" sound performance (première) curated by Xing as an ART CITY event (ARTE FIERA), which took place on the 31st of January 2019, entailed a quality assessment of the huge marble entrance - about 3000 m^3 - of the historical building (see fig. 2).

The aim of the present study is to evaluate the acoustics of the rationalist atrium during a contemporary music performance through acoustic simulation techniques. A 3D virtual model of the atrium was created and then imported in the acoustic simulation software. A Geometrical Acoustics (GA) algorithm - ODEON Room Acoustics v. 15 [32] - was chosen as simulation approach.

The 3D CAD model of the atrium was realized with SketchUp modelling software according to state-of-the-art guidelines (see fig. 3) [33, 34]. During the modelling process a reduction of the complexity of the geometry is usually done for computational efficiency. In the present case, considering the rationalist style of the architecture, drawing the model was quite straightforward.

The performance by Florian Hecker involved a series of nine T10 d&b audiotechnik loudspeakers, to envelop the audience (see fig. 2). The directivity factor Q of each loudspeaker may be assumed equal to 20, since 90° and 35° are the dispersion angles of the horizontal and the vertical directivities. Each loudspeaker played one channel of a multi-channel composition, resulting in dynamic and spectral variation among sources. The music was composed with Matlab and performed through Supercollider. The signals are coded as 32-bit floating point, allowing a very high dynamic range. Selecting 40 seconds from an excerpt of "SynAsTex Korrektur" composition, the spectrograms of two out of nine channels are shown in figure 4. As can be seen, Hecker's electronic compositions may show components in a wide frequency range and very high differences in the dynamics between the channels - more than 50 dB.

In the virtual model, nine sound sources were placed following the same layout of the actual performance (see fig. 5), including the corresponding heights, orientations, and directivities. For the aim of the present study, to analyse the sound field behaviour within the atrium, a virtual grid of 380 receivers was set at 1.5 meters above the floor.

The 3D model and the material properties of the atrium are available in a free repository [35]. They can be useful to compare various music contexts through multiple-input-multiple-output auralizations, employing multi-channel anechoic signals [36, 37]. The model can also return the former acoustics of the original configuration of the atrium, whose ceiling was reflective [28]. The whole buildings has been declared an intangible cultural heritage by Italian Authorities. The acoustics of the former hall can be considered as an intangible cultural heritage as well; and it could be virtually replicated, like it has been done in similar works [16, 38, 39].

2.1. Calibration of the virtual model

The material properties play a key role during the calibration process, as accurate values are required for reliable simulations. It was preferred to use a minimum number of material layers to reduce the uncertainty resulting from the assignment of absorption and scattering coefficients. Hence, the virtual model was organized in six layers according to the main construction materials (see tab. 1): marble, plaster, false ceiling, glass, masonry, and furniture.

According to reference studies [40], the calibration process was developed in the following steps. In a first phase, absorption coefficients were taken from databases [41] and applied to the surfaces of the model. The values corresponding to the false ceiling may depend on the particular mounting, e.g. on the air-cavity width between the false ceiling and the ceiling.

In a second phase, a measurements campaign was done according to ISO 3382 [42] to tune the materials properties in some frequency bands, as the false ceiling at mid-low frequencies. The sound absorption of this material may affect the sound intensity distribution [43], increasing the attenuation of sound energy versus the source-receiver distance. This corresponds to a non-diffuse sound field condition [44, 45] as could be expected from the presence of single and double heights. To quantify the influence of the false ceiling, the sound energy distribution was measured along a line (see fig. 5). Therefore, during the measurements the microphone receivers were placed with increasing distance from the sound source, according to ISO 14257 [46]. The measurements were done using an omni-directional sound source, whose power level was measured according to ISO 3741 [47]. The sound source was placed in a central position, in-axis with the line of receivers and impulse responses were measured for each source-receiver pair.

In a third phase, the omnidirectional sound source present during the calibration measurements was introduced in the virtual model. Temperature and relative humidity were recorded during the measurements – whose values were, respectively, 16 °C and 40% – and then set in the numerical simulations. The model was firstly calibrated based on sound strength values along the line of receivers. The calibration process was carried out by matching the results of the measurements to the ones of iterated simulations. For that, some absorption coefficients taken from previous literature were slightly adjusted, yet chosen within a reliable range of values, and the acoustic properties of the false ceiling were fine tuned. It should be also noted that, at high frequencies, the sound absorption of air is not negligible, due to the low sound absorption of boundary materials in the atria [13].

As shown in figure 6, the spatial attenuation in the octave band centred at 1000 Hz has a larger slope than the 2000 Hz band. This probably means that the absorption coefficients of the false ceiling show a bell behaviour in frequency, centred around 1000 Hz. Moreover, the panels of false ceiling are very thin, and they are mounted with an air gap, contributing to another broad absorbing peak at 125 Hz.

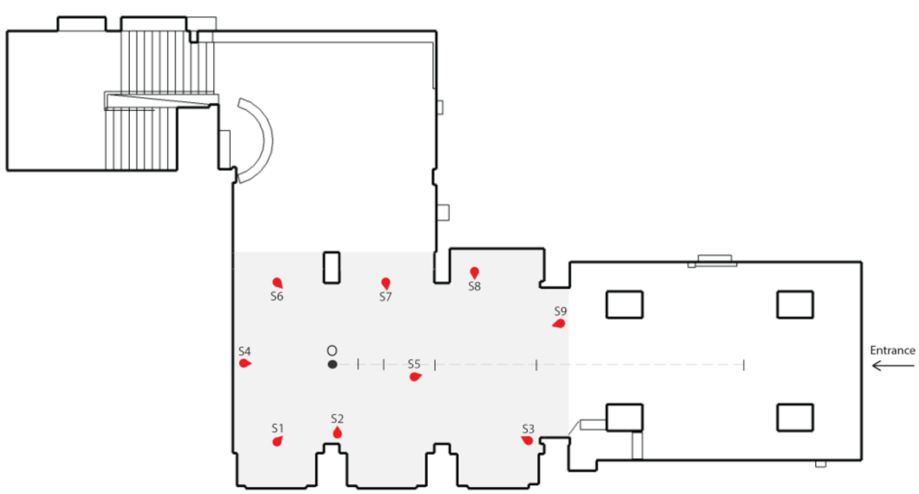

Figure 5: Plan of the atrium of the historical building under study: positions of the sound sources (S1 - S9) set by Florian Hecker during his sound performance. IRs were measured in the calibration process, placing omni-directional sound source (O) and receivers along the dashed line. Grey zone corresponds to the audience area during the performance (see fig. 2).

Table 1: Absorption (α) and scattering (s) coefficients for all the materials involved in the simulation [32, 41].

Materials	Surface		Absorption/Scattering coefficients					
	%		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Marble	40	α	0.01	0.01	0.01	0.01	0.02	0.02
		s	0.01	0.01	0.01	0.01	0.02	0.03
Plaster	18	α	0.02	0.02	0.03	0.04	0.05	0.05
		s	0.01	0.01	0.01	0.10	0.20	0.25
False ceiling	16	α	0.28	0.23	0.17	0.17	0.12	0.08
		s	0.01	0.01	0.01	0.01	0.02	0.03
Glass	11	α	0.18	0.06	0.04	0.03	0.02	0.02
		s	0.01	0.01	0.01	0.01	0.02	0.03
Masonry	5	α	0.08	0.09	0.12	0.16	0.22	0.24
		s	0.01	0.05	0.15	0.35	0.45	0.50
Furniture	4	α	0.30	0.25	0.20	0.10	0.10	0.15
		s	0.01	0.10	0.45	0.65	0.75	0.85
Audience	6	α	0.16	0.29	0.55	0.80	0.90	0.92
		s	0.01	0.10	0.45	0.65	0.75	0.85

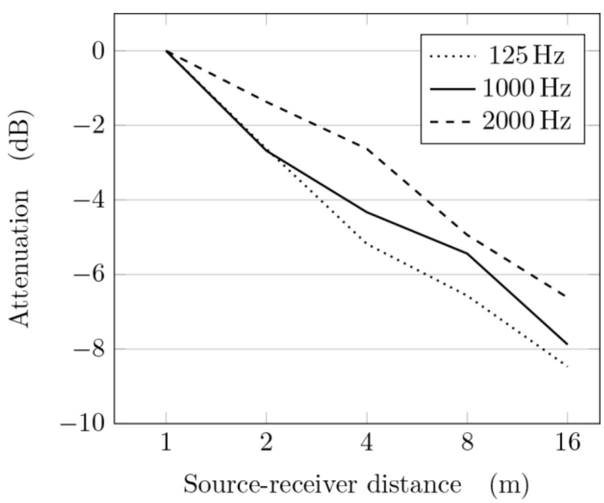

Figure 6: Measured spatial attenuation in the atrium. The resulting DL_2 value, as average on 125-4000 Hz octave bands, is equal to 1.9 dB.

The scattering coefficients employed as input values in the calculation setup are chosen according to the roughness of the surfaces and thus, they are quite low due to the characteristics of the main materials of the atrium (see tab. 1). The main materials - marble, plaster and glass - are pretty hard and reflective surfaces with a low degree of roughness. Therefore, it should be noted that the scattered sound field in environments like atria is mostly determined by the edge diffraction, i.e. directly by the geometry and the shape of the architecture.

The impulse response length was set at 4000 ms, the number of rays used in the calculations at 20,000 and the transition order between early and late reflections at 2.

2.3. Sound field behaviour with the audience

Inside atria there are not seats and the audience is standing. Consequently, sound absorption is mostly due to the audience, with drastic differences in the acoustics of the unoccupied versus occupied conditions (see fig. 7). It should be also noted that the air absorption is as well influenced by the audience, whose presence can increase the temperature and the relative humidity, and by the daylight conditions [48]. In the simulations, the audience was modelled as a box 1.5 meters high above the floor, similarly to the usual practice employed for modelling the presence of seats [32]. The estimated amount of people corresponds to a density of 1 person/m^2 over the area considered (see fig. 2 and the corresponding grey area in fig. 5). Sound absorption coefficients referred to such density were applied to the surfaces of the 'audience box', as well as a scattering coefficient equal to 0.7 at mid frequencies.

3. The listening experience of a multi-channel performance in a non-diffuse sound field

It is well known that in a diffuse sound field - when the source-receiver distance is higher than the so-called critical

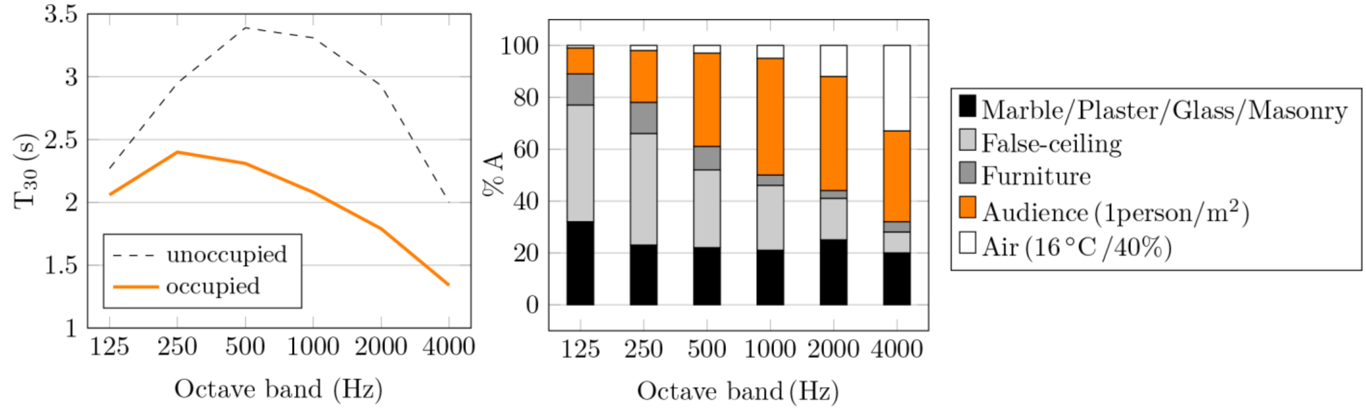

Figure 7: On the left, mean values of simulated reverberation time (T_{30}) in the unoccupied and occupied conditions. On the right, percentages of equivalent absorption area (% A) of the materials involved in the simulations

distance - the sound level values are quite constant in space. In this condition, the sound fields of multiple sound sources are 'blended', returning the same sound pressure level over the space - outside of the critical radius of each sound source.

In a non-diffuse sound field, the sound levels throughout the room vary more than in a diffuse sound field. It should be noted that this happens even if the sound sources are omnidirectional. In the case under study, the sound-sources – spatially spread in the atrium – show high directivity at mid-high frequencies. Both the strongly non diffuse field and the high directivity of the sound sources influence the listener's experience depending on his/her location. The spatial distribution of A-weighted sound pressure level in the occupied condition is shown in figures 9 and 10, considering, respectively, a single sound source and all the sound sources involved in the performance.

Assuming the semi-reverberant theory hypothesis, the critical distance is expressed as $r_c = \sqrt{QR/16\pi}$ m. In the present case, the critical distance of the atrium equals to 7.5 meters, considering R as the equivalent absorption area A, the reverberation time at mid frequency in the unoccupied condition (T_{30}=3.4 s), the volume of the entrance (V=3000 m^3) and the directivity of each sound source (Q=20). This means that within 7.5 meters from each loudspeaker the direct field is prevalent rather than the reverberant field.

The simulation results in figures 9 and 10 show that when the listener is moving among the spread sound-sources, he is primarily hit by the direct sound of the nearest sound source. The high directivity of the loudspeaker contributes to make the early reflections of the same sound source weaker and attenuated. The late reverberation – from all the sound sources – arrives after several milliseconds. For these reasons, the listening experience of multichannel sound performance is very different from the one of symphonic music in a concert hall. Even if in both situations there are several sound sources blended by the environment, in a concert hall the envelopes of signals coming from distributed sound sources (i.e. instruments) are preserved by early reflections, influencing the spaciousness and other subjective parameters [49]. Given the high directivity of the sound sources, there are fewer reflections from side walls, so the same envelopes are preserved by direct field only. This can be confirmed by the simulation of the lateral fraction (LF_{80}) values throughout the space (see the spatial distribution in fig. 11), with low values corresponding to few early reflections. It is the placement of the loudspeakers, rather than the hall geometry, that contributes to the spaciousness, which is a predominant factor in the listening experience of electronic compositions [50]. Numerical simulation is a viable tool for predicting and adjusting some of these effects during a multi-channel sound performance. In this case, the peculiarities of the rooms and the predominant effect of the occupancy were considered. Numerical simulation, then, can be beneficial to the composer or the performer during the performance design, e.g by optimising the distances between the sound sources in order to provide a more immersive listeners' experience.

Final considerations concern the peculiarities of composition in the context of the atrium under study. The composer should consider both spatial and temporal behaviour. Concerning the spatial properties, the composer minimises the effect of the hall, influencing the listener's spatial impression through the multi-channel composition. Moreover, some techniques used by Florian Hecker, such as spectral aliasing [51], should be related to the temporal responses of the hall. For instance, they can influence the time delay between two sound sources of the threshold time between the direct and the reverberant part of the impulse response.

4. Conclusions

The paper discussed the peculiarities of an electronic performance in a non-diffuse field through the results of simulations. In 2019, the monumental atrium of one of the most relevant Italian rationalist building hosted a première of the "SynAsTex Korrektur" performance by German composer Florian Hecker. The setup of the performance was re-created in a GA model. Due to the strongly non-diffuse properties of the atrium, the model was calibrated by the spatial decay of the sound energy. It was shown how the audience contributes to about half of the total acoustic absorption of the environment. The latter two instances – respectively, the non-diffuse properties and the audience absorption – have particular effects on the listening experience. This involves only the direct fields from multiple sound sources placed in the space and the late reverberation. Early reflections do not contribute to the listener experience, as opposed to the standard approach of concert hall acoustics.

Finally, these acoustic peculiarities were discussed based on Florian Hecker's music.

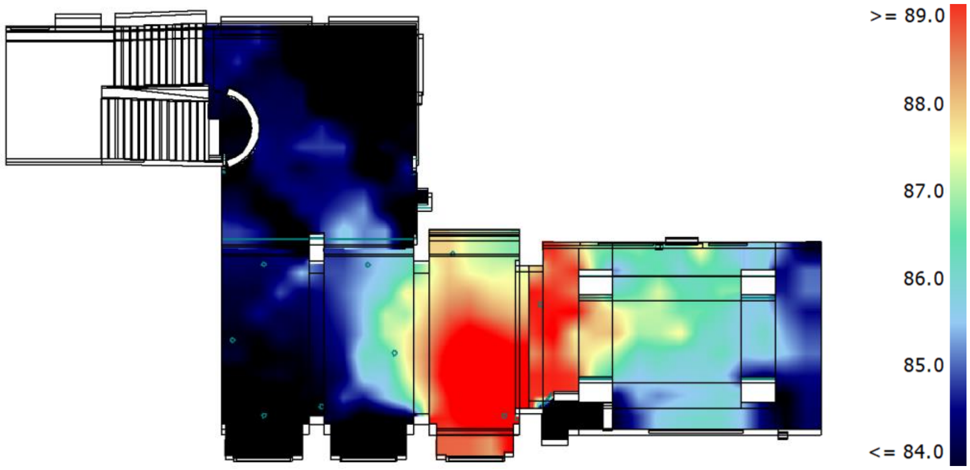

Figure 9: Simulated values of A-weighted sound pressure level (SPL(A) in dB(A)) in the occupied condition with the loudspeaker S3 active (see fig. 5).

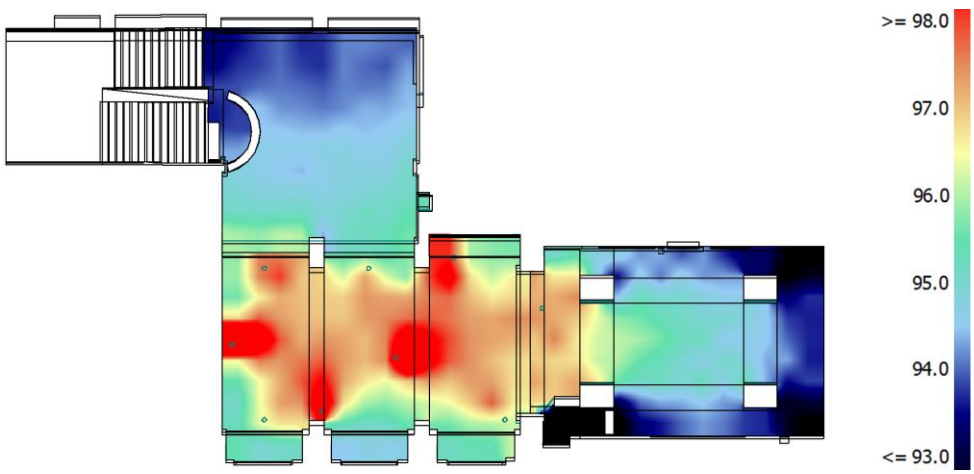

Figure 10: Simulated values of A-weighted sound pressure level (SPL(A) in dB(A)) in the occupied condition with nine loudspeakers active (see fig. 5).

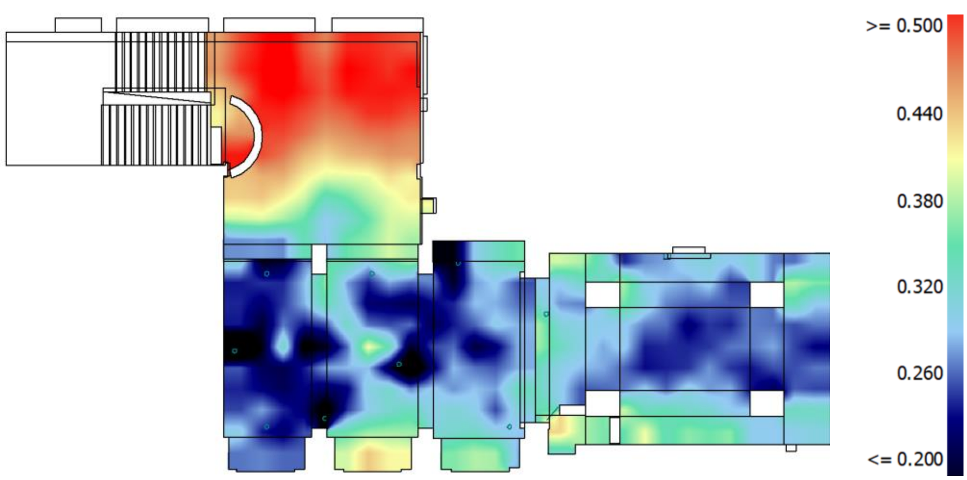

Figure 11: Simulated values of lateral fraction (LF_{80}) at 500 Hz in the occupied condition.

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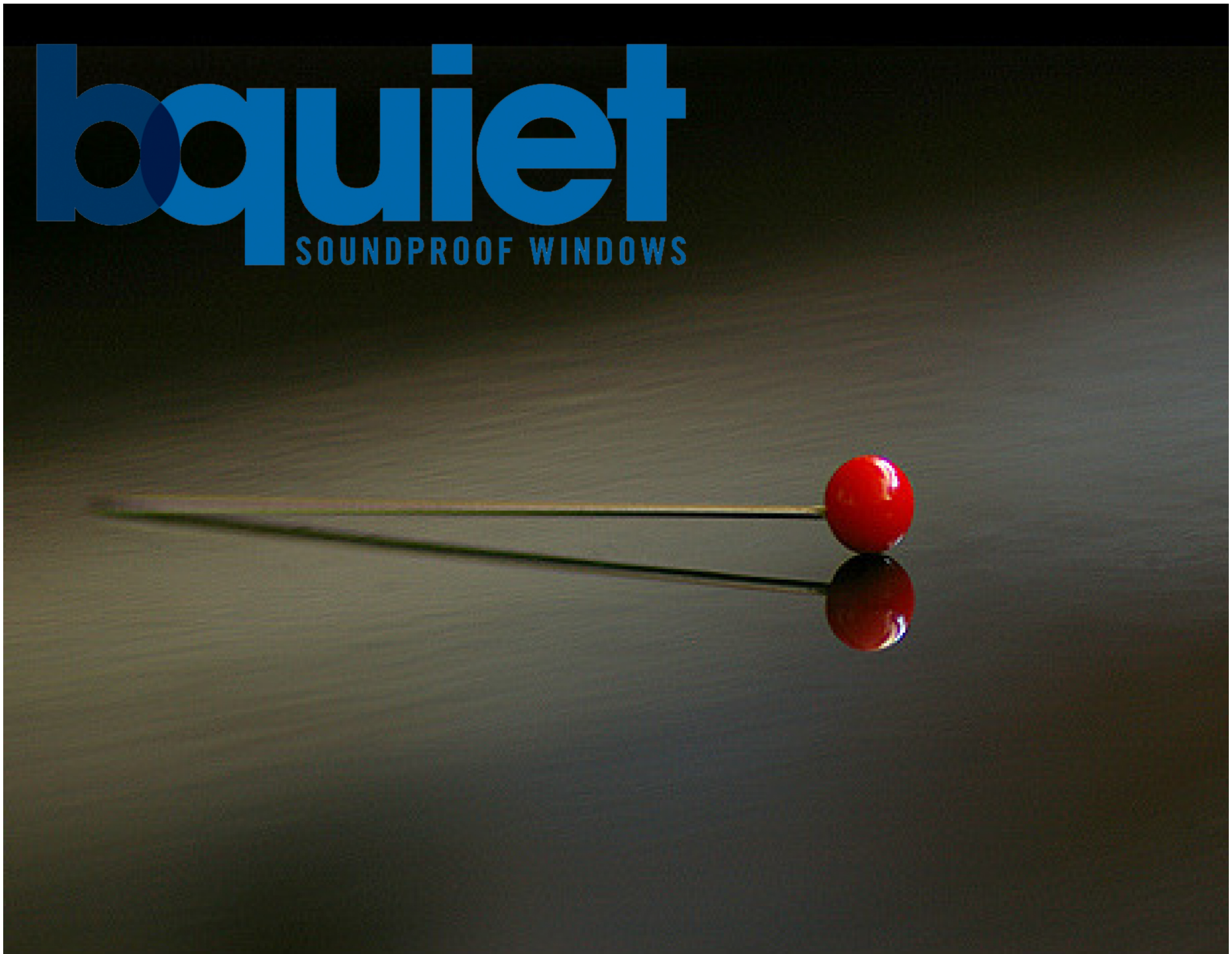
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