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Analysis of the Acoustic Conditions in a Tent Structures

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Abstract

Shape variability and material diversity belong to the modern trends in architecture and civil engineering. A significant progress can be seen in the usage of woven, non-woven and foil membranes, so called architextiles. Textile membranes find their applications as both interior and exterior structures offering interdisciplinary challenges for architects, artists, engineers, chemists, physicists, textile designers and material scientists. Lots of ongoing research is done in terms of their durability, thermal physics properties, tension from wind, weather and also in terms of the energy aspects. In the field of acoustics, most of the studies relate to the sound insulation and absorption properties influenced by the mass changes, structure perforation, tension in the membrane etc. In general, there is much less information on acoustic comfort available in comparison with the thermal comfort. Nevertheless, the physical properties of membranes allow for building of large-span tents, suitable for variety of cultural events and concerts, where the acoustic quality inside the hall and sound insulation properties of its exterior structure are one of the main building physics requirements. This article brings a literature overview on room acoustic problems in halls built out of woven and non-woven membranes, and shows an example of a measurement and analysis inside a temporary tent structure built for a cultural event.

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1. Introduction

Modern textile structural skins are definitely a interesting component in a modern architectural design. They have many, for an architect, attractive properties, such as good flexibility, low weight, high tensile strength, sufficient penetration of daylight into building interior. Many different types of textile membranes already exist and probably the most interesting from the acoustical point of view are multilayer membranes, micro perforated absorbers and double-leaf absorbers [1, 2]. Different kinds of textile membranes exist, but the most common are woven, non-woven, knitted structures and their combinations. Their acoustic properties are typically considered from both, room acoustics (e.g. sound absorption) and building acoustics, (e.g. sound insulation) point of view. In the architectural design, both, room acoustic and building acoustic aspects contribute to the overall acoustic comfort.

If we look at the state of the art we will see, that quite some research has been done in the field of material research [3-15], but only little information can be found in literature about the acoustic comfort in the tent structures [16, 17].

Sound engineers often indicate occurrence of flutter echoes and uncomfortably high degree of reflectivity at middle and high frequencies in tent structures. The basic impermeable textile membranes have typically higher reflection properties at high frequencies then in low frequencies, where the membrane effect might play a role. Logically, the sound in a tent structure is coloured by sound reflections, enhancing high frequencies and causing so called “sharp sound”. If we look at the reverberation time in a large tents in frequency domain, we should typically observe a kind of “inverse” situation in comparison with ordinary rooms built out of hard walls (with quasi flat sound absorption) where a “boomy” sound will be present due to low absorption at low frequencies. (Note that flat sound absorption coefficient at room surfaces will not result in a flat reverberation time over all frequency range. Low frequencies will reverberate longer due to significantly lower air absorption at f < 1000 Hz). From the sound insulation point of view, the penetration of sound waves through the boundary walls will be obviously higher in a tent structures in comparison with classical “stone-based” buildings.

In this article we aim at the assessment of the acoustic condition in a temporary tent structure used for music performance. This pilot study compares measurements *in situ* with simulations in ray-based algorithm and discusses the way the input data for these kinds of simulations should be considered. In ray-based room acoustic simulations, typically the sound absorption properties α (-) together with scattering coefficient is given. In case of the textile membrane we rather speak about the reflection and penetration of sound than about sound absorption. In this article we will illustrate how it is possible to simulate “room” that is built out of textile membrane.

2. Description of the experiment

2.1. Description of the case study

The tent space analyzed in this article has a floor dimension of 10 x 30 m and height varying from 2,2 to 3,7m. The description of the tent, together with measurement and simulation setup is shown in the Figure 2. A total surface area of interior surfaces is S = 801 m^2 and the volume of the room is V = 880 m^3. On the floor there was a light carpet. Other surfaces are made out of PVC tarpaulin textile material. The mentioned tent–space was built up for a music event in the castle park of Merode in Germany.

To understand the acoustic conditions in the given space better, and to confirm or reject the general hypothesis, the room acoustic measurements were performed in situ, followed by simulations in Odeon software. Because measurements were performed only few hours before the music festival, some acoustic treatment have been already made in a room, such as relatively heavy curtains (ordinary wedding drapes, with typical absorption coefficient α_{1000} = 0,57~0,75) have been placed on the ceiling and walls in the tent. As a matter of fact, we had no opportunity to measure the effect of curtains on a ceiling in situ and only the situation with opened and closed curtains on walls were performed. However, simulations with and without curtains were performed later on.
In this article we show the comparison of three different variants.

Variant 1: “open” curtains (walls are only partially covered by folded curtains), measured and simulated;
Variant 2: “closed” curtains (walls completely covered by curtain), measured and simulated;
Variant 3: “without” (without covering), only simulations were performed;

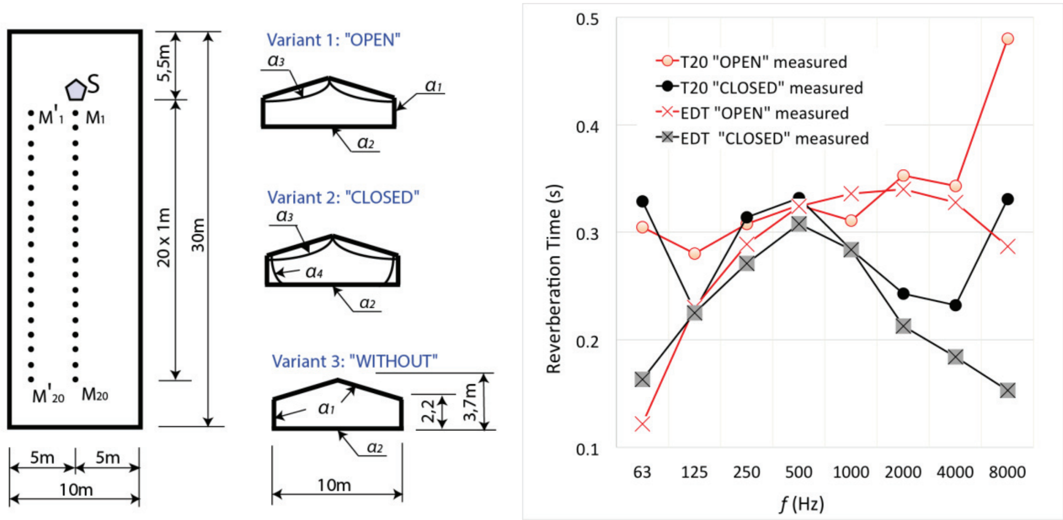

Fig. 1. Dimensions of the tent with the indication of sound source (S) and microphone (M) positions (picture-left) and the average values of the reverberation time T_{20} and Early decay time *EDT* (picture-right)

3. Measurements and Simulations

3.1. Measurements

Impulse response measurements were performed in situ (Figure 1) according to the ISO 3382 using Dirac software. Measurements were done for 2 position of the Omnidirectional sound source (Q source) and 20 microphone positions (microphone type B&K 2642). Parameters such as Early decay time *EDT*, Reverberation time T_{20}, Speech transmission index *STI* and Sound strength *G* values were calculated from the impulse responses. Based on the measured reverberation time, the reflection coefficient and consequently the sound absorption coefficient α(-) was estimated. The sound pressure level decay with distance was compared with free field situation by means of *G* values. The reverberation time T_{20} shown in the Figure 1 – right was calculated as an average value from 20 microphone positions (indicated on the Figure 1 – left).

3.2. Simulations

ODEON software10.2 was used for the room acoustical simulations. This software uses a hybrid algorithm where two geometrical methods are combined to predict the impulse response of a virtual room. The simulation of the room impulse response (RIR) is in principle performed in two steps. The first part, which contains information about early reflections, is calculated by combining the image source method and early-scattered rays.[18]. In the second part of the RIR, the late reflections are calculated by a modified ray-tracing algorithm that also takes into account the scattering coefficient of the involved surfaces.

Table 1. Sound absorption coefficient of tent surface.

Name	63 (*Hz*)	125 (*Hz*)	250 (*Hz*)	500 (*Hz*)	1000 (*Hz*)	2000 (*Hz*)	4000 (*Hz*)	8000 (*Hz*)
α_1	0,7	0,79	0,73	0,66	0,69	0,55	0,51	0,19
α_2	0,03	0,03	0,09	0,25	0,31	0,33	0,44	0,44
α_3	0,63	0,89	0,72	0,64	0,75	0,82	0,83	0,42
α_4	0,63	0,89	0,72	0,64	0,75	0,82	0,83	0,42

Simulation model (Figure 2 - left) was calibrated based on the averaged measured reverberation time T_{20} (Figure 1 - right) for Variant 1 – “open”. The sound absorption coefficient used in the simulations is shown in the Table 1. Three different variants (“open”, “closed” and “without”) were later simulated and analyzed from different point of view. In all models, scattering coefficient of all surfaces was 0,05.

3.3. Theoretical values

Measurements and simulations are finally compared with theoretically calculated values too. For theoretical calculations of reverberation time, the well-known Sabine formula was used [19]. From calculation of the sound pressure levels at certain distances from the source, the so-called Sabine-Franklin-Jaeger (SFJ) theory was used (1).

$$L_p = L_W + 10\log\left(\frac{Q}{4\pi r^2} + \frac{4(1-\alpha)}{\alpha \cdot S}\right) \text{ (dB)} \tag{1}$$

where L_W (dB) is the acoustic sound power level, Q is the directivity coefficient of the sound source (for omnidirectional source value Q = 1), r (m) is distance between the source and receiver α (-) the average sound absorption coefficient and A (m^2) is the total absorption area in the room. In this article we show the distribution of sound levels by means of G-values (Sound strength). When G is used, the calculation formula (1) can be rewritten as:

$$G = 31 + 10\log\left(\frac{1}{4\pi r^2} + \frac{4(1-\alpha)}{\alpha \cdot S}\right) \text{ (dB)} \tag{2}$$

4. Results and discussion

All the results in the Figures 2 and 3 are displayed in a following way. The theoretically calculated values are in all situations indicated as lines (“dotted” for situation “WITHOUT”, “dashed” for “OPEN” and “full line” in case of “CLOSED”). Measured results are shown as circles and simulations as other symbol types. The different variants are distinguished also in colors, red for Variant 1 (OPEN), black for Variant 2 (CLOSED) and Variant 3 (WIHTOUT) in a blue color.

4.1. Measurements

The measurements show, that the reverberation time in the tent is in general very short, T_{20} = 0,3 - 0.65 s (Figure 1-right). We can see that both variants have rather short reverberation time and that closing the curtains will make the T_{20} to drop with more than 10% only at frequencies higher than 2 kHz. Although the *RT* values for octave band 8000 Hz are in room acoustics standardly not measured, we show these values as they are significantly higher then the values in other octave bands, which is not typical for ordinary rooms with porous materials (such as plaster, bricks or stones) applied on interior surfaces. Although the reverberation time at 8 kHz is less then 0,7s, and thus one won’t perceive it as a long reverberation, the sound reflections from textile room-boundaries will be coloured and the sound present in the room might be perceived as “sharper” in comparison with an ordinary room. Interestingly, the *EDT* is very similar to T_{20} in the range between 125 Hz and 4kHz, but at 8kHz the trend is very different from T_{20}, where *EDT* gradually drops with increasing frequency (similar what would happen in an ordinary room). This is due to a fact that the *EDT* is calculated from a decay of sound between 0 and -10dB and thus first reflection, typically coming from ground is very important. Floor in the tent is porous material (carpet) with high absorption at high frequencies. If we look at the measured sound pressure level decay with distance, given through G (dB) values (Figure 3 – left) we can conclude that the correspondence with theoretically calculated values according to the SFJ theory is very good for microphone positions at distances up to 14m from the sound source. For further positions, the diffused field theory predicts too high values. At 20m, the sound level is around 5dB lower than the theory. Speech intelligibility in the tent was evaluated according to STI values. Measured STI (without noise) are very high, at all positions above 80%. This is due to short T_{20} in the room.

4.2. Simulations

The Figure 2 – right shows the average T_{20} for 3 different variants. We can see that the Sabine theory correspond relatively well with simulation (with less than 0,1s difference) in the whole range. Simulated values of *G* (dB) correspond very well with measurements (Figure 3 – left) and yield lower values than theory at distances >14m. We can see that although the reflection coefficient of the textile structures is not very high, and reverberation time is very low, the presence of tent in comparison with free field situation will increase the sound levels at 20m from the sound source with 10 dB for situation "WITHOUT" and with 6 dB in case the curtains on the walls would be closed.

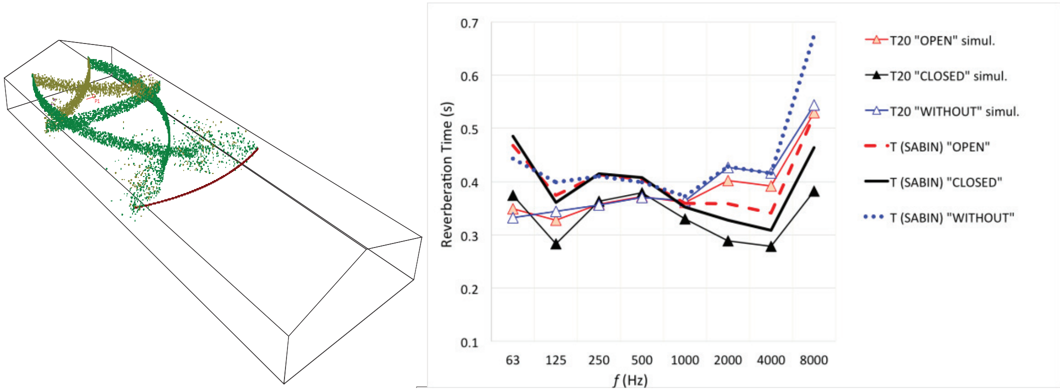

Fig. 2. 3D model from Odeon software. and simulated reverberation time T_{20}, comapred with theoretical calculation according to the Sabine theory

In classical rooms, speech intelligibility is often influenced by the reverberation more than by the background noise in the frequency range of speech. It is thanks to the often sufficient sound insulation properties of the walls, floors and ceiling. In the tent objects, especially in those built for the temporary events, the sound insulation of the structure is often a problematic issue. In this article we have compared simulations of three different background noise levels $L_{w,low\ BKG}$ = 41,9 dB(A) and $L_{w,BKG}$= 61,9 dB(A) with a frequency spectrum based on the standardised traffic noise values ISO 717-1. STI without noise indicated in squares in the Figure 3 –right. STI in a presence of a low background noise (40 dB), typical for an ordinary room and for noise 60dB that would be realistic in a situation if the tent would be built in a city area. The results show, that in case of the STI with realistic noise (Figure 4-right) the speech intelligibility would drop significantly and without an amplification system it would be impossible to use this room for giving a speech or a presentation.

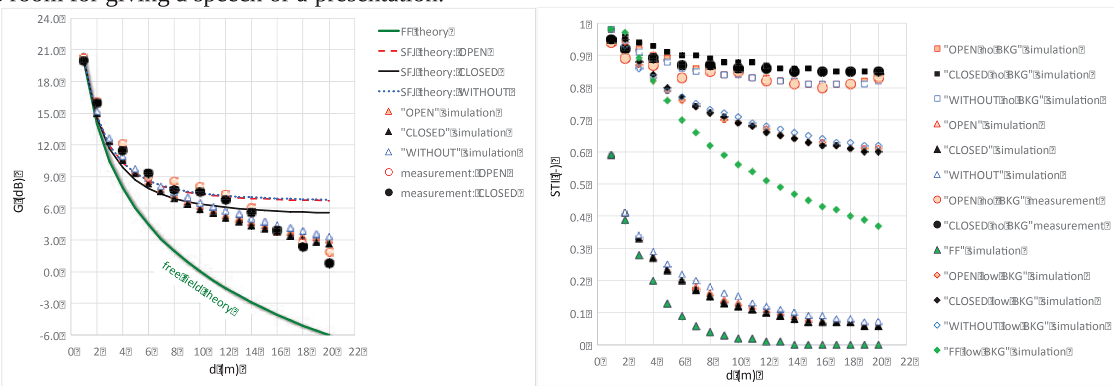

Fig. 3. Sound Strength G (dB) decrease with distance from the sound source (left) and STI with and without background noise as a function of a distance from the sound source

Conclusions

Reverberation time in our case study yields significantly higher values of reverberation time at octave band 8kHz in comparison with other frequencies. Closing or opening of heavy curtains placed on the walls will influence the reverberation time only at frequencies above 2 kHz. If we look at the Sound pressure level distribution in the room we will observe that the measured and simulated values correlated very well. This means that the sound pressure levels can be successfully simulated in ray-based algorithm in similar types of rooms. However, the SFJ diffused field theory overestimate the sound levels at receiver positions > 14m from the source. Speech intelligibility without taking the background noise levels into account would lead to a very big error. It is therefore important to know where the tent is build. Based on the results obtained from this case study we can conclude that a tent structure without electroacoustic support won't be an ideal place for music. Also the attenuation of sound with distance will not make it possible to follow a speech of a person at further distances.

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