ACOUSTICAL MEASURES IN HISTORICAL BUILDINGS AT THE EXAMPLE OF THE CATHEDRAL OF NÜRTINGEN

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ABSTRACT
At the example of the Cathedral of Nürtingen, will be demonstrated, which acoustic measures are possible and necessary in historical buildings to get an acceptable acoustical situation for both, speech and music. Assuming from roomacoustical solutions will be shown, which are judged as uncritically under the aspect of preservation of historical monuments Therefore, new acoustic elements will be introduced, roomacoustic measures and public address system requirements will be described.

INTRODUCTION

Aesthetics plays an important role in architecture. But architecture can not be reduced to optical properties. In rooms where acoustical events will be performed, the aesthetics of the room have to justify to both, to optical, and acoustical requirements. We see the room, and we take place listen in the room. The room will influence our perception. In the middle of the perception stands the human person. And as the human person can not be divided in an optical or acoustical perceiving subject, the room should not be divided in optical, or acoustical priorities. In historical buildings, a preserving aspect is added. The original outfit of the room should be preserved. But often, the so called "original outfit" has been changed during the centuries and during the restorations and rebuildings. Often it seems to be difficult to decide which period of restoration has to be preserved. But one thing has not changed during the centuries: the expectations and requirements of personal perception. So a cathedral has to fulfil the expectation of an impressive room-experience, the audibility of speech and the pleasure of musical performances. In this project and this article we will give an important place to the acoustical situation without forgetting the optical aspects of the restoration of a sacral historical building.

HISTORICAL NOTES

The Cathedral of Nürtingen was built in 1024 or former and destroyed in 1286 by Rudolf von Habsburg. In 1509 the building of the present cathedral was finished. The first organ was built in 1530. A second organ in baroque style was added in 1724 in the choir and replaced in 1885/6 by an organ in an newgothic style. The first extensive renovation was in 1895/6. In 1936, a new organ was built on the westgallery. During the second extensive renovation in 1964 the original galleries around the cathedral have been taken out figure 1 and 2 shows the state before. In 1973 a new organ has been built on the westgallery [1]. In the Year 2000 a big fire has disturbed the interior of the house, the organ, and the public-address-system [2]. All these renovations and changes, motivated by mainly optical interests, have modified the acoustical situation. So there are reasons for the assumption this situation before 1964 with the wooden galleries would have had a better acoustic situation than the Situation afterwards. Wooden Installations often work as absorbing elements for deep frequencies.

Figure 1: The inside of the Cathedral of Nürtingen in 1960 with gallery

Figure 2: The inside of the Cathedral of Nürtingen in 1960 with gallery and wooden panelling in the choir

SITUATION

The old public-address-system was destroyed by fire. For selection and planning the public-address-system, roomacoustical measurements have been necessary. There exists no ideal public-address-system for each room. A public-address-system which works very well in one room can produce an acoustical disaster in another room, if the acoustical situation is very different. So the requirements for such a system can't be seen without a look at the acoustical state. The requirements for the public-address-system have to be found, and proposals for acoustical modification have to be made to reach satisfying conditions.

RECUIREMENTS

The cathedral is used for devin services, celebration of masses, church celebrations and also for concerts. For understanding the sermon, a good speech recognition is important. Therefore the clarity C_{50} has to be a value above 0, and the articulation loss of consonants has to be lower than 15 % For sacred music and concerts the acoustical situation should allow a sufficient clarity and definition. A summary of the importantst values is shown in chart 1. The requirements for the public-address-system will depend on the acoustical measurements.

RT	r_H	BR	C_{50}	C_{80}	Al_{cons}
2,2 s – 4,5 s	Large as possible	1,1-1,3	> 0	0 - 6	< 15 %

Chart 1: Summary of the requirements

The reverberationtime of 2,2 s will give a good acoustical situation. But the audience will expect a longer reverberationtime, because its experience in large cathedrals. A too short reverberationtime will be perceived as unnatural. So a reverberationtime of 4,5 s in the maximum can be accepted. For selection and planing the public-address-system the effective diffuse field-distance is more Important than the reverberation time. The values of the clarity C_{50} and C_{80} will be not mentioned furthermore, because the essential factor for the planing of the public-address-system is the articulation-loss of consonants Al_{cons}.

GEOMETRICAL SITUATION AND MEASSURING POSITIONS

The Cathedral has a volume of 7648 m³, a ground-area of 645 m², and a surface-area of 2596 m². About 250 m² of the ground-area are covered with chairs and 136 m² of the surface-area are windows. For the measurement of the roomacoustical situation 4 positions of loudspeakers, and 12 positions of microphones are used. The positions of loudspeakers and microphones are shown in figure 3. Microphone MC and Loudspeaker LC are in the choir. Microphone M0 and loudspeaker L3 are below the gallery. The other microphones and loudspeakers are in the nave The loudspeakers have omnidirectional radiation. Reverberationtime, transfer-function, and impulse response were measured. From this datas the interesting values - shown above - have been calculated.

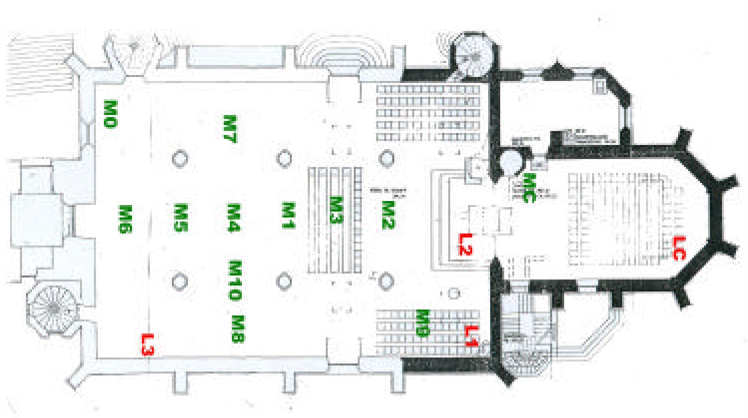

Figure 3: Ground-plan of the Cathedral of Nürtingen with measuring points: M: Microphone-positions, L: Positions of Loudspeakers

ROOMACOUSTICAL MEASUREMENTS

The cathedral can be distinguished under acoustical aspects in three regions: the nave, the choir room, and the area below the gallery. The reverberation time is measured for a first overview in octave bands. At this time the cathedral was nearly empty. No furniture and especially no chairs were in the room. The measurements in this three areas are shown in figure .3-5.

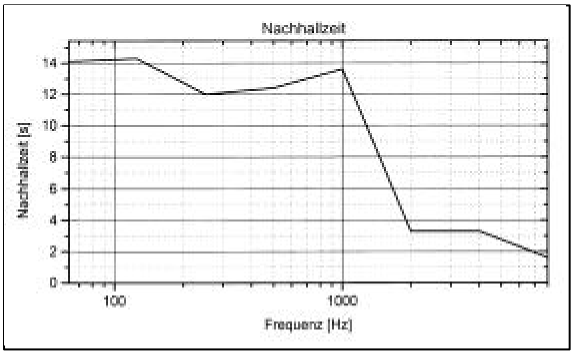

Figure 3: Reverberationtime measured in the nave before acoustical measures

Reverberation time of the nave

From 63 Hz until 2000 Hz the reverberation time has very high values. At 125 Hz the highest value of RT of 14,3 s is measured. From 2 kHz to 8kHz the reverberation time is very low. You will find its minimum at 8 kHz by 1,6 s. The mean value amounts to 9,3 s.

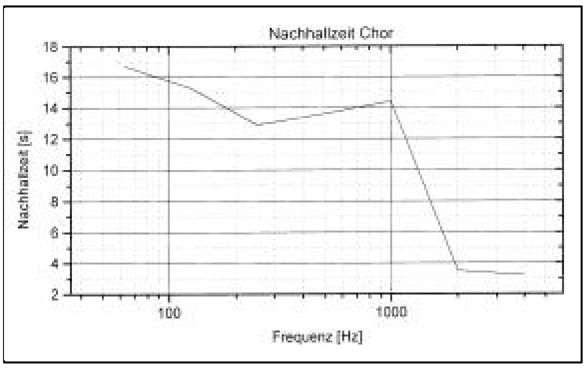

Figure 4: Reverberationtime measured in the choir before acoustical measures

The choir room

To include the special acoustical properties of this room, the measurements will be done in the choir room. The results are shown in Figure 4. In the choir room the longest reverberation time has a value of 16,7 s at 63 Hz and has its minimum at 8000 Hz with a reverberation time of 1,5 s. The low difference between the reverberation time of the nave and the choir room will be explained by the coupling of the nave and the choir room. The higher value of reverberation time in the choir room may be an effect of resonances between the walls in the choir room. About this the transfer-function (not shown in this article) will give more information.

The area below the gallery

Below the gallery the reverberation time is the longest in the whole cathedral with a value of 16,9 s at 1 kHz. Also in this area the reverberation time decreases at 2 kHz very steep and reaches his lowest value at 8 kHz with a value of 2 s. In the area from 63 to 1000 Hz the reverberation time is distinctly longer than in the nave. This effect can be explained by resonances and the existing of standing waves between floor and gallery. The analysis of the transfer-function and of the impulse-response confirm to this.

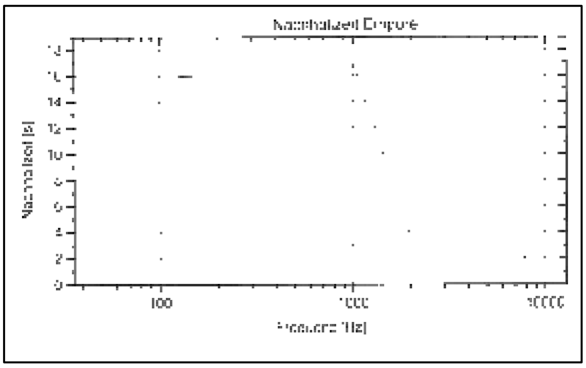

Figure 5: Reverberationtime measured in the choir before acoustical measures

ROOMACOUSTICAL SOLUTIONS

The possibilities of acoustical measures in the case of historical buildings are limited by the optical requirements. So the acoustic elements should influence as few as possible. This can be realised by two ways: 1. by redesigning elements that are usually in the room, or by designing aesthetically fitting objects for this room. Both of these ways were gone in this case. The chairs have been designed for absorbing frequencies in the middle range. New absorbing elements have been designed for absorbing deep frequencies. At high frequencies no additional absorption is needed.

Chairs

The chairs themselves gives some possibilities of acoustical designing. The surface of the chairs is perforated. The diameter and distance of the holes is calculated on the basis of Helmholzresonators with the variation of no closed air-volume behind. The positioning of the chairs also gives a structure of a lattice which can be calculated like the holes in the surface of the chairs with the two distances a and d like shown in Figure 6. Further more, the down side of the chairs is covered with carbon-wool, a porous absorbing material which works in mainly two aspects: Damping the Helmholz resonator of the perforated chairs and like conventional porous absorber with a distance to the floor for eliminating reflections from the stone covered floor.

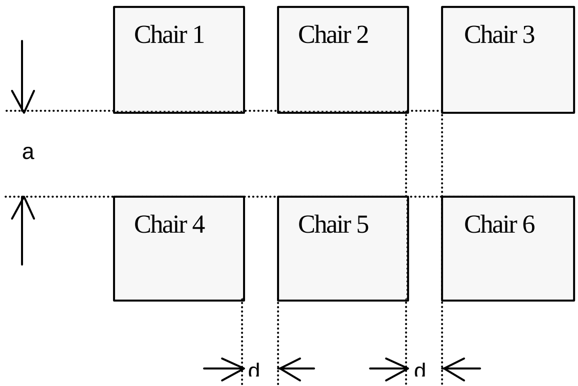

Figure 6: Arrangement of the acoustical designed chairs

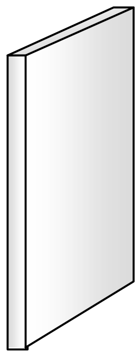

Figure 7: Sketch of the absorbing element for deep frequencies, with a thickness of about 11 cm

Deep-Absorption

The reverberation time at deep frequencies is much too long. At high frequencies, it is too short. This will be perceived as a deep rumoring and missing brilliance. Especially during the playing of the organ with its deep frequencies and during orchestral performances this will be very disturbing. The place for additional acoustic elements is hardly limited. Optical compatibility is essential. So the needed acoustic elements have to absorb at deep frequencies, not to absorb (less than the with the elements covered wall) at high frequencies. Has to be optical unobtrusive and aesthetically refined. Conventional Absorbers don't fulfil all this, so a new acoustic element has to be developed. A new acoustic element made of a new material (translucent plexiglas, so called "transatco") for an old cathedral.

THE PUBLIC-ADDRESS-SYSTEM

The public-address-system should not stimulate the diffuse-sound-field. So a high directivity – especially at deep frequencies - is profitable. The loudspeakers should be placed near the audience. By using many loudspeakers a signal-managing-system is needed to avoid differences in sound travel time. The selected loudspeakers [3] fulfil the requirements. Figure 8 shows the position of the loudspeakers, and figure 9 the articulation-loss-of-consonants.

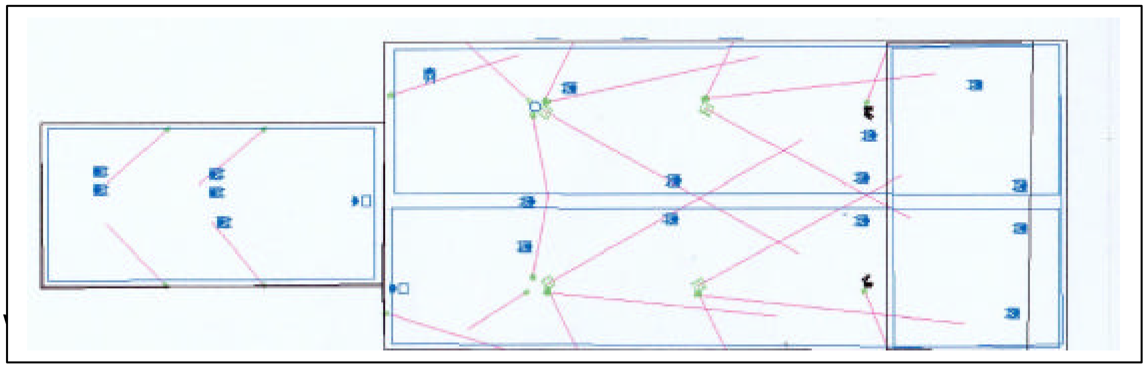

Figure 8: Positions of the loudspeakers

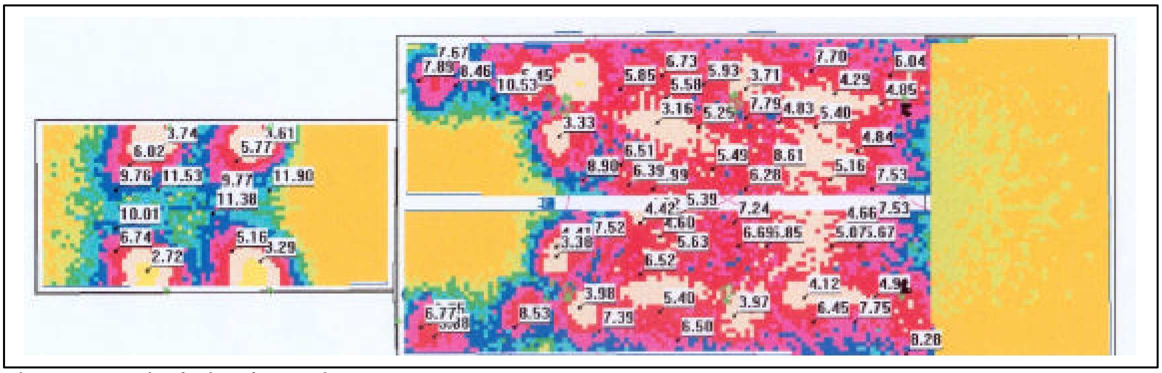

Figure 9: Articulation loss of consonants

NEW MEASUREMENTS

After the first step of the renovation of the cathedral the walls have been cleaned and painted, the benches were covered with pads, and the acoustic designed chairs have been installed. The measurements of the reverberation time after these first measures are shown in Figure 10. In opposite to the measurements in the raw cathedral, the tree viewed regions – nave, choir, below gallery - have nearly the same reverberation time. This means, referring to the reverberation time, all regions have the same good, or bad acoustic. Chart 2 shows an overview on the mean values of the reverberation time in the tree regions. The difference

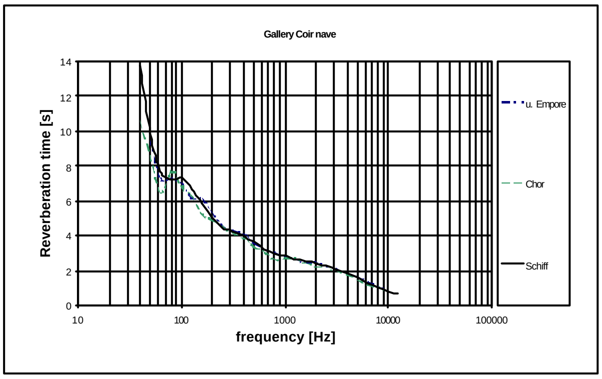

Figure 10: Reverberationtime measured in the nave, below the gallery and in the choir after first acoustical measures

between the raw rooms is 2,1 s, and after the first steps 0,4 s. The mean value of all three region in the raw room is 10,3 s, and after the first measures 4,4 s. This means a reduction of the reverberation time of about 6 s without any significant influence in the optic of the cathedral. In figure 11 the reverberation time of the two states, raw room and after first measures is shown in octave bands for better comparison of the two measurements. But not only the reverberation time is an important value to describe the acoustic of the room in this case. So the diffuse-field-distance r_H, the bass ratio BR and the articulation loss of consonants Al_{cons} are compared in Chart 2. Figure 12 shows the restored church with the acoustical designed chairs and the new public-address-system

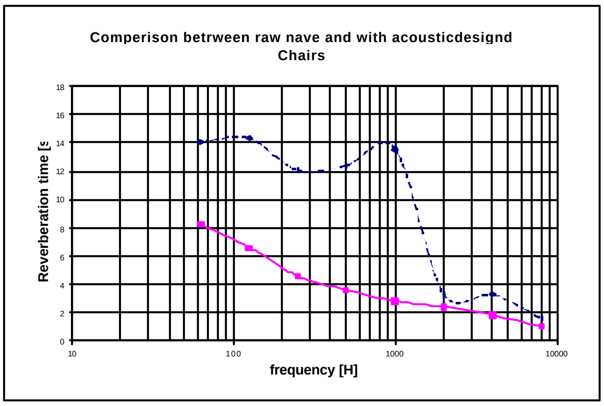

Figure 11: Comparison between the reverberation time in the nave before, and after the first acoustical measures

	Abbreviation	Raw room	After first measures	difference	Aimed values
Reverberation time Nave	RT	9,3	4,6	4,7	4,5
Reverberation time Choir	RT	10,1	4,3	5,8	4,5
Reverberation time Below gallery	RT	11,4	4,2	7,8	4,5
Reverberation time Mean value	RT	10,3	4,4	6,0	4,5
Effective diffuse-field-distance nave	r_H	1,6 m	4,4 m		
Effective diffuse-field-distance choir	r_H		4,5 m		
Effective diffuse-field-distance below gallery	r_H		4,4 m		
Bass ratio	BR	1,02	1,74		1,1 – 1,3
Articulation loss of consonants	Al_{cons}	83,7 %	8,2 %		< 15 %

Chart 2: Comparison between the raw room before acoustical measures, and after the first acoustical measures

CONCLUSIONS

A solution of the acoustical problems could be found, which fulfils aesthetical criterions as well. The reverberation time RT could be reduced from 10,3 s to 4,4 s. the articulation loss of consonants Al_{cons} could be reduced from 83,7 % to 8,2 %. The problem of the reverberation time at deep frequencies and with the bass-ratio BR can be solved by the proposed transatco absorbers.

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