SIMULTANEOUS VISUAL AND ACOUSTICAL PERCEPTION IN ROOM ACOUSTICS

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ABSTRACT

A study presented which was aiming at understanding of audio-visual interaction in a drama theatre. Computer graphics software was used to create a high-quality visualisation of an architectural student design study “theatre on a ship”. This space can be changed from a closed space to a open-air theatre. In parallel the three conditions of the space (open, semi-open and open-air) were simulated by room acoustical computer software (CAESAR). Subjective tests using speech material were performed to study the relation and interaction between the visual and the acoustic impression. The results show that “dry” acoustic conditions are only acceptable in the visual open-air situation. In contrast, the well-optimised reverberant condition for the closed space was preferred in all three visual conditions, even in the open-air situation. The results must be confirmed in further studies, but a first hint is that it might be advantageous to add electro-acoustic reverberation in open-air theatres.

INTRODUCTION

An interesting question for an architect is the audio-visual interaction in performance spaces. When speech or music is performed in closed rooms, we expect a certain reverberation time. The reverberation time can even be roughly estimated from the visual impression of the room volume and the wall absorption. At least, we can perceive unconsciously, whether a room matches our visual impression or not. Dry speech in a church sounds extremely unnatural. Long decaying music sounds unnatural in a small speech theatre. The latter example is interesting, since it is no problem to enhance the decay time of small rooms by using electro-acoustic installations, for instance in small multi-purpose halls. It is hence important to consider that basic room shape, size, seating, lighting, colours and surface finishes have a direct impact on the visual impression, at the same time some of them have, too, an effect on the acoustically perceived quality. During the stages of planning and construction the architect concerns himself with many functions. If the acoustical design is one of these functions, especially in planning of spaces, where acoustics plays an important role, good sound quality will be assured.

Up to now the criteria for “good” room acoustics have been essentially investigated and a number of quantities are objectively measurable (ISO 3382). This was, however, so far taken into account only isolated and accomplished mostly under laboratory conditions. The interaction with the simultaneous perception of visual and acoustical impressions was examined by Winkler [1] regarding consequences for architecture.

In this paper experimental studies are described which are focused on the interaction between room acoustical scenes with respect to “matching” and “non-matching” visual and auditory events. One practical aspect related to this approach is whether acoustically dry spaces like small rooms or open-air theatres should be made reverberant by electro-acoustic means or not.

1 ARCHITECTURAL DESIGN OF ACOUSTICAL PARAMETERS – A CASE STUDY ON A SWIMMING THEATRE

Room acoustical computer simulations allow predictions sound fields in rooms and determination of results of several room acoustical parameters like EDT, T10, T20, T30, clarity (C80), definition (D50), lateral fraction (coefficient) (LF, LFC), centre time and stationary level G. To obtain these parameters, the room must be created geometrically either directly in this program or with the help of another CAD software. The software used is CAESAR [2]. The creation of this surface shape can also be done by using a drawing program such as AUTOCAD, which enables to draw with little expenditure, then export it to the acoustical program. This method was used in this study due to the complexity of the room examples and due to the necessity of high-quality visualization.

Our case study is related to a project, which has be defined as exercise for students at the Faculty of Architecture of Aachen University. This project has special objectives. It is a swimming theatre, it can carry the audience and a small group of actors and stage technicians. It moves along a river with the help of a separate drive unit (push boat). The project goal was that the theatre must have more flexibility with its shape and construction, so it can be closed when the weather is bad and be opened when it is nice. In this way it should be possible to travel short distances to different places with relatively small expenditure and also to change the structure and dismantling, and to give a performance adapted to each situation.

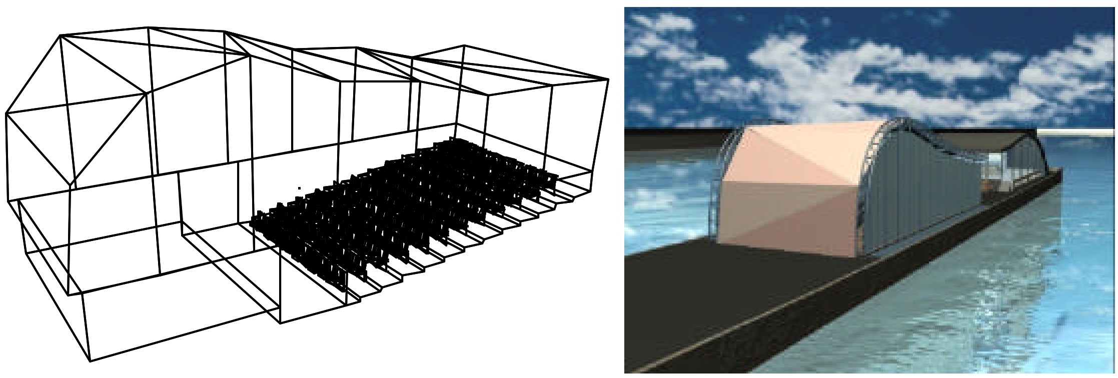

Figure 1. The selected design of the swimming theatre with folding lateral lamellas and folding ceiling

For the actors the theatre boat is a place for life, work and meeting with their audience. The approximate sizes of the theatre area are as follows: for the auditorium (seats for 120-150 Persons) ca. 200 m^2, for the stage 70 m^2 and for back stage 70 m^2. Fig. 1 shows one solution which has be designed as part of a student’s project. It was selected to perform the current investigation.

ROOM SHAPE AND OPENING STATE

Changes of the theatre are restricted to the lateral walls and ceiling with three variations in this case study. The first variation is the theatre with closed lateral partitions and closed ceiling, the second variation is with semi-open lateral partitions and a closed ceiling, and the third variation is without lateral partitions and without ceiling. In Fig. 2 these three variations are illustrated.

Figure 2. The different three variations for the designed theatre,
(left) closed room, (middle) semi-closed room, and (right) open space

Each of these different states has an effect on the acoustical parameters like reverberation time, speech intelligibility, music clarity, sound pressure level, etc. Fig. 3 shows the differences in the impulse responses (from a sound source on the stage to a central point in the audience area) for the three variations.

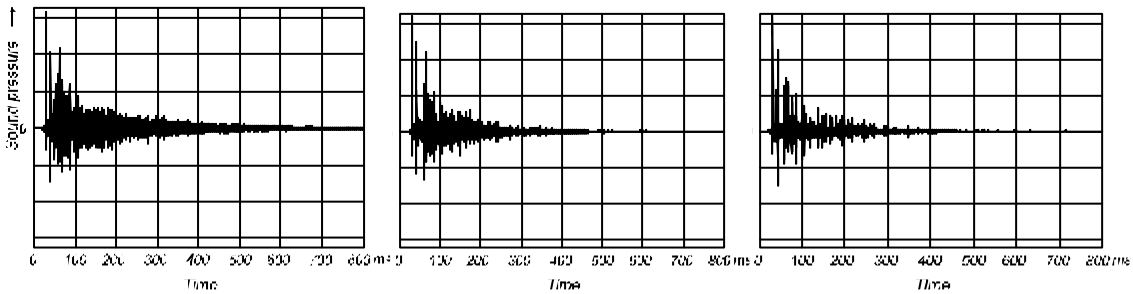

Figure 3. The different simulated impulse responses for the designed theatre by the three different variations:
(left) closed room, (middle) semi-closed room, and (right) open spaces

2 PREPARATION OF THE EXPERIMENT

The aim of the experiment is to evaluate and compare subjectively the acoustic impression, to judge the agreement between the simultaneously presented visual and acoustic impression, and to know what is the degree of the human satisfaction. In order to accomplish this experiment and to achieve the demanded goal, the selected design of the mobile theatre must be processed in more detail visually and acoustically. On the one hand, the design is completed by using different computer drawing tools to prepare a 3D drawing to obtain an at most as possible realistic visual impression. On the other hand, we use the possibility of auralisation of sounds in these simulated variations of the theatre.

VISUAL PRESENTATION

To make the visual presentation for the designed theatre the program “3D-Studio” was used, which allows to create materials with their textures, different lighting systems with shadows, furniture and persons, and finally to produce an animated movie. In order to create a realistic visual effect for a theatre situation, a scene from the comedy “Leonce and Lena” by GEORG BUECHNER (1836) was chosen, produced by KARL GUTZKOW 1987 [3]. Fig. 4 shows the attempt to create similar scene by using of 3D-studio program.

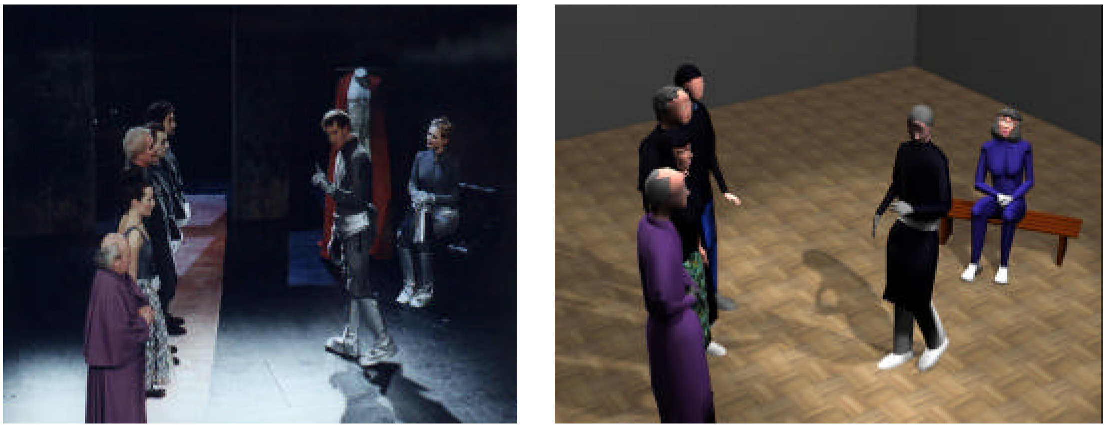

Figure 4. An original and a created scene for the comedy (Leonce und Lena)

With using of the “3D-Studio” software more realistic presentations like animation can be made. In this study three short movies (20, 9, 40 seconds) were created, which show firstly the closed theatre, secondly the opening of the side walls by rotation of the lateral lamellas, and finally how the ceiling and lateral lamellas are folded and removed. Fig. 5 shows some scenes of the last movie which contains 1000 scenes.

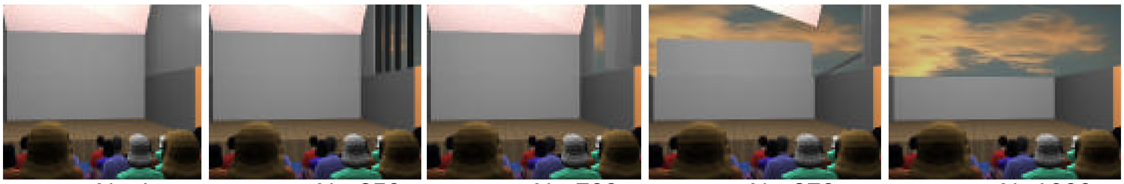

Figure 5. The sequence of some scenes from the third movie “opening”

All these procedures give finally an acceptable visual impression for the test subject according to the situation in a real theatre.

AURALISATION

The first assumption for material properties were suggested by the designer (student) without any consideration on the room acoustics of this room. Three situations of the room (closed, semi-closed, open) were studied. Then materials of some planes were changed to achieve optimal reverberation times and another three variations simulated. For each variation with the same positions of the sound source and receiver (listener) binaural impulse responses were obtained.

In order to create realistic acoustical impressions for the test subjects, some texts were selected from the comedy described above. These texts have be recorded in an anechoic chamber as theatrical performed speech. These signals are the input data for the reverberation process by convolution with the binaural impulse responses. For this experiment one sentence (2 seconds) and one paragraph (34 seconds) were selected, each of them was convolved with the six impulse responses. If the resulting signal is replayed by a suitable device (e.g. headphones or binaural loudspeaker technology), one obtains a realistic impression of the room acoustical properties.

3 AUDIO-VISUAL EXPERIMENT

For comparison of the objective acoustical parameters which have be simulated with aid of computer and the human judgement, an experiment will be accomplished. This experiment is at first part a listening test to evaluate the degree of the conformity of the acoustical quality for several short speech signals with a theatre performance. In the second part it is a visual and listening test to judge the "match" of the visual impression with the acoustical impression at the same time, and also to evaluate the overall impression for both senses.

From the preceding visual and acoustical procedures we have now the possibility to test these results subjectively. It is important to create a theatre atmosphere for the test subject to get unbiased answers. Therefore the visual exhibition (scenes and movies) were projected on a big screen (2.7 x 2 m^2) at a perpendicular distance from the position of the test subject of 2.3 m. That means that at this distance the visual angle of the subject covers only the screen to its outmost dimensions. For the playback of the sound signals (convolution of the dry signals with the different impulse responses), these are presented to the listener by two loudspeakers in an anechoic environment via a cross-talk cancellation system, as be showed in fig. 6. In a real theatre one dose not use headphones, therefore the loudspeaker method was preferred in this experiment.

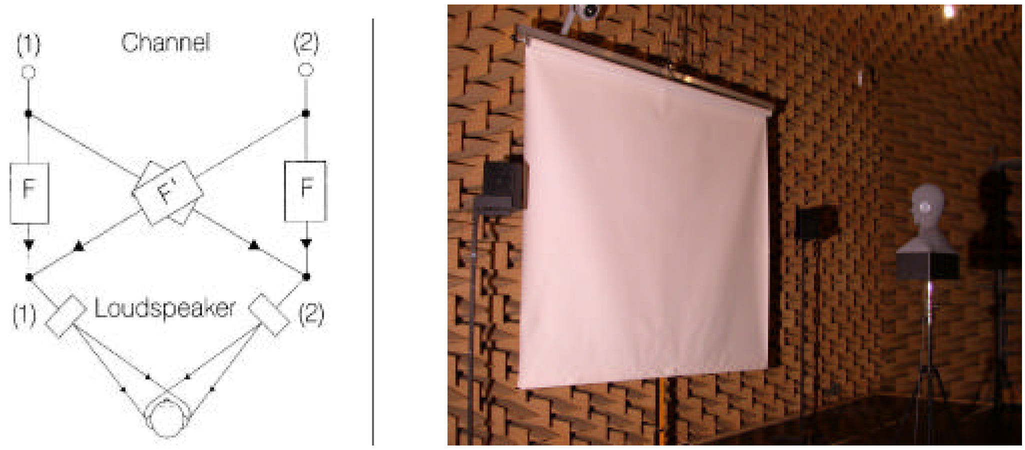

Figure 6. Principle of cross-talk cancellation in loudspeaker reproduction of binaural signals and position of the test person (dummy head) in an anechoic chamber (right)

QUESTIONNAIRE

The following notation representing the sound examples in the room variations is used.

Signal A	Closed room
Signal B	Closed room, after acoustical treatment
Signal C	Semi-open room
Signal D	Semi-open room, after acoustical treatment
Signal E	Open space
Signal F	Open space, after acoustical treatment

Table 1. Acoustic signals created for the different room conditions

Fig. 7 shows the experiment with the third visual variation (open theatre) with the six symbols for the different signals.

Figure 7. Experimental prosecution at the third optical variation in an anechoic room

Under consideration of the duration of the experiment (about 25 minutes) and the sequence and complexity of the questions, a questionnaire has be designed and tested. After some information about the test subject (name, age, native language and his theatre attendances), and according to explanation of the aims of this experiment, the questionnaire has be divided into three parts:

1) Preliminary test: How good is the acoustic quality for a theatre performance? In this part the test subject listens to six short signals, which have be convolved with the different impulse responses, and for each signal he denotes the degree of sound quality (very bad, bad, middle, good or very good), this classification was made more detailed in numbers from 1 to 50.
2) How well does the sound impression fit with the visual scene? In this part the test subject sees one of the three movies. Then a fixed scene of the theatre play is presented, and he listens to three of the signals (B, D, F, all after acoustical treatment), and marks the degree of the conformity between what he sees and hears.
3) Judgment of the overall visual and acoustical impression. In this part the test subject sees the same fixed scene of the theatre play, but he listens to three of the long signals (B, D, F, all after acoustical treatment), and denotes the degree of his satisfaction with the different impressions.

The second and third tasks are to be repeated for each one of the three visual variations. Finally, to check reliability, the preliminary test in the first task was repeated.

4 RESULTS

32 test subjects participated in the experiment.
81% are native German speakers (in which the signal have been recorded).
13% attend theatres frequently and 62% attend sometimes.
50% work in acoustical science and 30% work in architecture design.

In the first part the acoustic quality of the signal is to be evaluated for the three different variations of the theatre, in order to find the favourable sound for a theatre performance. According to the reverberation time of each variation of the room, the subjective evaluation of the room acoustical quality results in an optimum reverberation time for a theatre performance between 0.5 and 1 second. In fig. 9. the mean values of the subjective evaluations for the acoustical quality with the reference to EDT at 1000 Hz are shown. These results confirm that reverberation times might be chosen little lower than proposed in literature without loss of acoustic comfort. With EDT being above 1 second, however, the loss of speech intelligibility causes more negative answers and reduction of the acoustic quality.

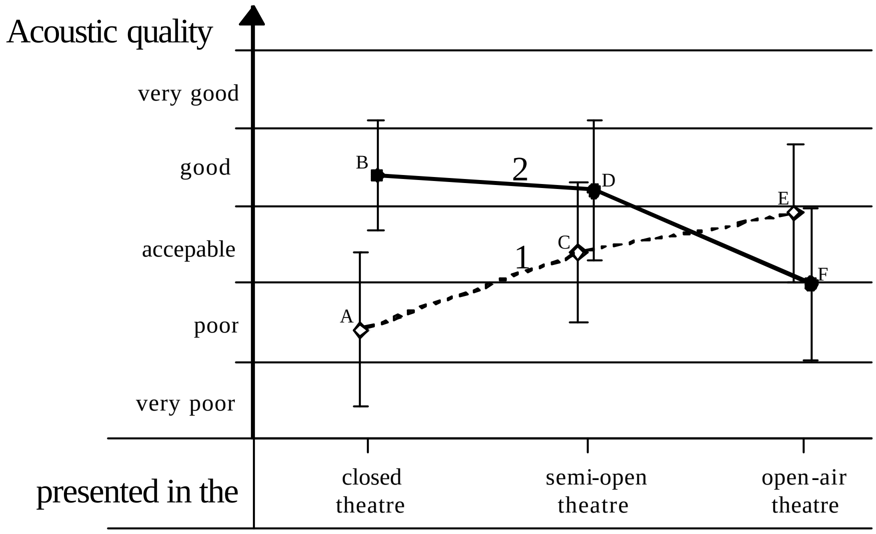

Fig. 8. Judgement of the acoustic quality of the signal listed in table 1.

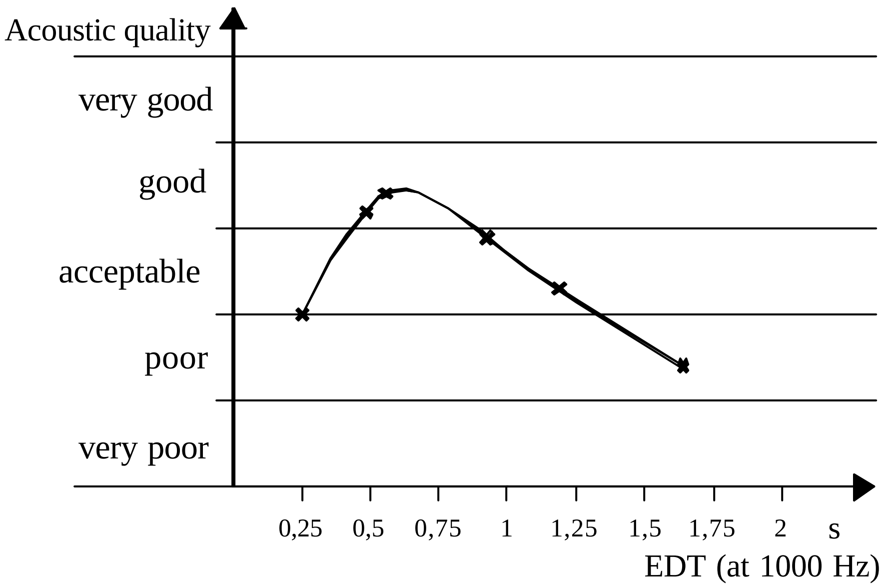

Fig. 9. Optimum range of Early Decay Time.

JUDGMENT OF SIMULTANEOUS VISUAL AND ACOUSTICAL IMPRESSIONS

Finally the three visual conditions of the acoustically treated room (B, D, F: closed, semi-open or open-air) were tested in all permutations of the audio-visual combination. The result is shown in fig. 10. The "dry" signal (F) including the impulse response for the open-air space gives a poor result if presented in the closed visual situation. It changes to acceptable, almost good, when presented with the open-air situation. This result can be expected, of course. In contrast, the best result (good) was given to the acoustics of the closed room (B). It changes slightly towards worse quality when it is presented with the semi-open and open space, but remains still "good". Situation D for the semi-open acoustics matches perfectly between the two other cases.

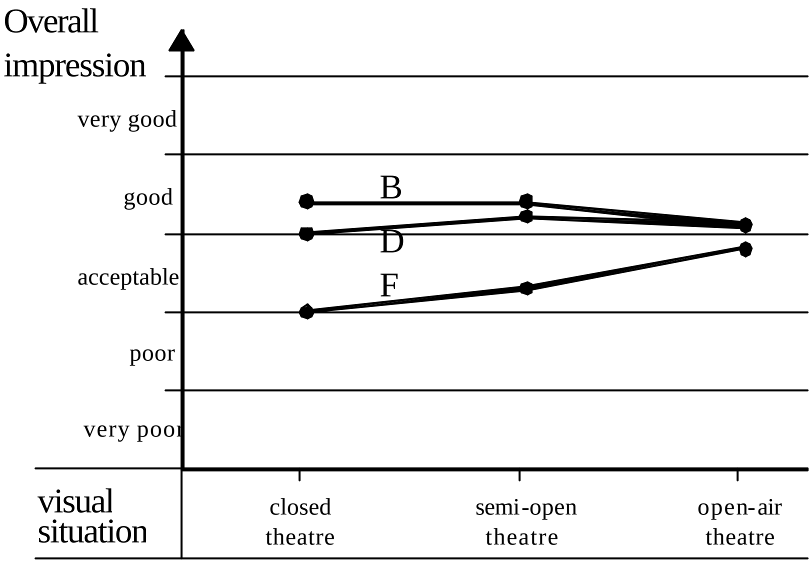

Fig. 10. Results of the subjective tests when dry (F), semi-dry (D) and reverberant (B) signals are presented in various visual situations (x-axis).

5 CONCLUSIONS

Audio-visual experiments were performed to study the interaction of the sound effects with visual impressions. The effects found are small but they give a first indication of the overall effect if listening in rooms. With too a dry acoustical situation the acceptance of drama theatre performance is poor, although speech intelligibility parameters like STI have best values. The preferred reverberation time was around 0.6 s. In the open-air theatre the reverberant signal, too, got the best judgement. This could not be expected in beforehand. Thus is might be recommended that open-air theatres should be equipped with artificial reverberation.

Further studies should be performed in order to achieve less statistical uncertainty. Some improvements in the experimental arrangement should be also considered, for instance using full 3D visual presentation in a virtual reality "cave" and dynamic crosstalk cancellation system with possibility of head movements.

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