7th AAAA Congress
on Sound and Vibration
22-23 September 2016, Ljubljana, Slovenia

Slovenian Acoustical Society

A tool for soundscape auralization of ancient archaeological sites

Marjan Sikora, Đana Grčić and Mladen Russo

Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture,
University of Split,
Rudjera Boskovica 32, 21000 Split, CROATIA, e-mail: sikora@fesb.hr

ABSTRACT

This paper presents the first stage of development of the soundscape auralization of ancient archaeological sites. The soundscape research has lately intensified, with different applications. We have focused on the application of audio augmented reality for enhancing the tourist experience of archaeological sites. In the first stage of our research, using a game engine, we have developed a tool for creating the soundscape of an archaeological tourist destination through augmented reality. With this tool, using virtual sound sources, we have simulated the real soundscape. Using mobile, location aware equipment, we have performed the auralization of this soundscape in situ. The fidelity of auralization was tested using the soundwalk method, by comparing the real soundscape with the auralization.

1. INTRODUCTION

The soundscape research has lately intensified, with different applications. The city in which our University is situated is famous for ancient archaeological sites, dating from Roman times. It is also a famous tourist destination. This inspired us to focus our soundscape research on the auralization of ancient archaeological sites, which are strong tourist attractors.

In this paper we present first two steps of our research: the development of mobile audio augmented reality system for enhancing the tourist experience of archaeological sites using soundscape, and its testing on the popular Split's promenade (Riva), which is situated in front of the Palace of Roman emperor Diocletian. The test was done in order to confirm the fidelity of the auralization. To confirm that our auralization is realistic we have performed a soundwalk of the real scene without audio augmented reality (AAR) to be the reference. Then we compared it to three soundwalks with AAR equipment. The first AAR soundwalk recreated the real soundscape, the second AAR soundwalk represented the soundscape of a busy street with building construction in progress, and in the third soundwalk participants walked in silence with headphones' noise reduction turned on.

The second author of this paper was a graduate student at the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, and parts of research presented in this paper were done as her graduate work.

The paper is organized in 5 sections: the first section is the introduction, the second section presents a survey of existing soundscape and augmented reality work, the third section presents our mobile soundscape augmented reality engine, the fourth section brings the results of the soundwalk testing, with a short discussion of the results and finally the fifth section is the conclusion.

2. SOUNDSCAPE AND AUGMENTED REALITY

The human experience of an environment does not depend only on visual stimuli. An important part of the experience is the soundscape, which ranges from natural sounds to sounds that occur in the everyday life in the city. The soundscape research is carried out in various areas such as psychoacoustics, noise pollution, improvement of the quality of life, protection of the environment and traffic. The goal of our soundscape research is to explore the possibilities and the importance of using soundscapes for the presentation of tourist attractions, particularly archaeological sites.

Soundscape

Soundscape is the sound or the sonic environment that enhances the immersive environment. The first use of the term soundscape was in 1969 by Southworth, an urban planner who used it to refer to the acoustic properties of cities, that help people relate to certain spaces. The term "soundscape" in its present meaning was first defined in 1977 by R. Murray Schafer in his book "Tuning of the world", who defined it as "a collection of all ambient sounds that reach the human ear". Lately the definition of soundscape has been refined by scientist such as Botteldooren [1] who states, that the soundscape is evoked by physical phenomenon of sound, but is not equal to it. The soundscape is a mental concept, and not just the sonic environment, because it is formed by the person's knowledge of the space that surrounds him, by the use of that space, and by its natural and cultural context.

One can look at soundscape from the auditory point of view as an equivalent to landscape considered from the visual point of view. These two components interact, and this gives us a tool to enhance the present visual environment. We have followed this path in our research, as we use the soundscape to enhance the visual impression of archaeological sites.

Researches use objective and subjective methods to analyse a soundscape. The objective methods include measurements and recording of sound for later processing. The typical subjective method is soundwalk [1]. The reason why subjective methods are important in soundscape research is the fact that soundscape is not equal to physical sound. Soundscape is the impression created by this stimulus, so to explore the soundscape one has to listen to people's impressions. So we decided to use it as the primary evaluation method in our research.

Soundwalk

Soundwalk is the standard method for a subjective measurement of the soundscape. This method was first introduced by R. Murray Schafer and means going on a silent walk, during which the subject must walk in silence observing the soundscape. At the end of the soundwalk the subject answers the questionnaire. This method is often used in research with minor modifications. For example, Bruce [2] does not interview his subjects at the end of the soundwalk, which lasts for about an hour, but rather stops the group every 10-15 minutes and performs a shorter query. Harriet [3] used structured soundwalk that consisted of 10 minutes of introductory talk, and warm-up, followed by 30 minutes' walk, and 20 minutes of shared reflections.

Researches extract the information from soundwalk using a questionnaire. Subjects answer the questions and from their answers researcher measures the different dimensions of the soundwalk. Special attention is needed when forming questions, because the linguistic description of cognitive processes in acoustics is not exact enough [4]. Different researchers use different set of questions, but the majority use the 7-point Likert type scale. For example, Harriet in [3] asked nine pairs of questions that listeners answered in 7-point scale: quiet/loud, weak/strong, harmonious/disharmonious, unique/common, warm/cold, varied/monotonous, soft/rough, pleasant/unpleasant, and comfort/discomfort.

Augmented reality, auralization and soundscape reproduction

Augmented reality (AR) is different from virtual reality, because it doesn't completely replace the real experience, but rather enhances the real environment with the synthetized one. In typical AR application, the virtual content is associated with real world information.

Although AR applications are primarily visual ones, acoustic versions are also present. Cohan first mentioned audio-augmented reality (AAR) in 1993. In the meantime, different applications emerged, like museum AAR guide, free field AAR navigational interface, geo-located sound art, and others. Kinayoglu [5] for example made an experiment at the University of California at Berkley, where participants wearing AAR equipment visited four locations at the campus. Participants gave seven-level numerical ratings of the acoustic pleasantness and compatibility with visual environment. Researcher performed AAR with headphones, and it was evident that people who regularly used headphones had less trouble adjusting to the testing equipment.

The important part of AAR is the auralization, since the reality is enriched with auralized sounds. Harriet in [3] investigates if one can use auralization to access the impact of noise treatment in urban environments. He performed auralization using the finite difference time domain (FDTD) simulation of the sound propagation over a noise barrier. Beside numerical models, researchers often use geometrical simulation [6]. The impulse response produced with the simulation is then convoluted by fast Fourier transformation (FFT). To get proper spatial clues of the auralized sound, binaural synthesis is performed with head-related transfer functions (HRTF). Instead of using convolution other filtering techniques can be used, to simplify and speed-up the auralization process.

3. SOUNDSCAPER - MOBILE AUDIO AUGMENTED REALITY ENGINE

We named our mobile audio augmented reality engine *Soundscaper*. We conceived it as an application in which a designer can create a soundscape for the chosen outdoor location on a PC computer, and then perform the auralization of designed soundscape on a mobile device using headphones. Created soundscape is georeferenced. Also, the created audio augmented reality takes the position and the orientation of the listener into account using positioning and orientation sensors on the mobile device. For the development of the *Soundscaper* we chose Unity, a cross-platform game engine. It uses 3D graphics API for the visualization of the scene, allows placing multiple audio sources into the scene, and can access the positioning and the orientation sensors of the mobile device. Program for creating the game environment in Unity is called Unity Editor.

Before creating the soundscape in Unity Editor, we prepared the map of the soundscape area in ESRI ArcGIS Desktop software. As the base map we used the ortophoto map from Croatian State Geodetic Administration WMS service. This map has the scale of 1:5000, was created in 2011 and is projected in the official Croatian projection-HTRS/96 TM. Using GIS software, we re-projected it in the universal UTM/33 projection and exported it as a georeferenced raster file. In Unity Editor we then imported it and used it as a material for a georeferenced terrain object. Besides the base map, a simple model of buildings on Split's Promenade was created using Blender tool for 3D modelling, and placed it on the map.

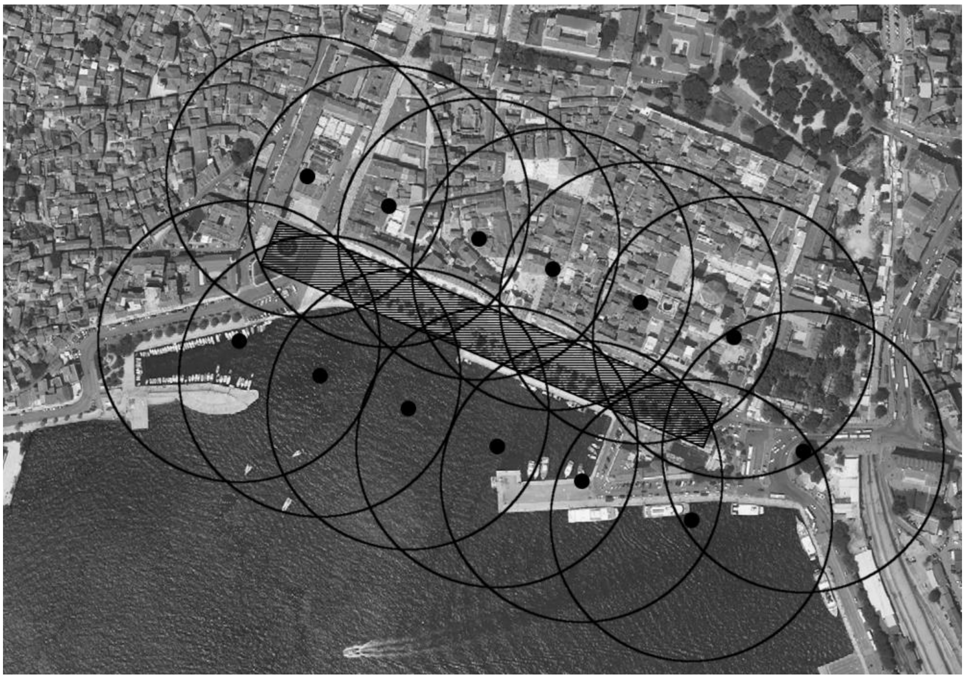


Figure 1. The area covered with soundscape (rectangular hatched area), and sound sources with their range.

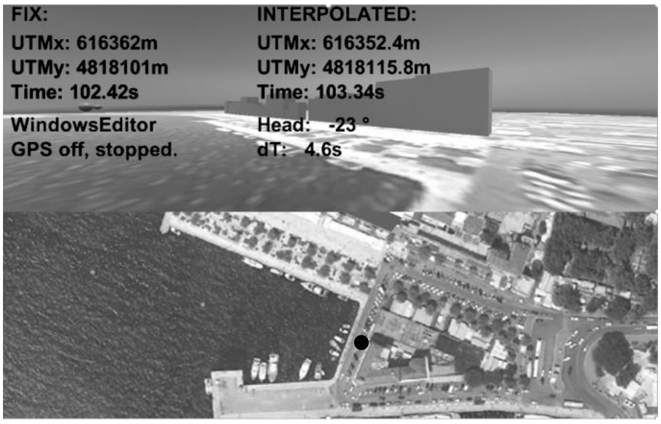
After creating visual components, we created more important, acoustic part of the scene. First we created omnidirectional audio sources, which are in Unity called *AudioSource* objects. We distributed them on the map, so we covered the whole target area with sound. Figure 1 presents the scene we created for Riva soundscape. The simulation area (hatched rectangular area) where sound sources create the soundscape is approximately 400m long and 40m wide. It is surrounded with 13 sound sources displayed as black dots, with their range displayed as circles.

For every *AudioSource* object in Unity, the designer can set the minimal and maximal distance where the user can hear it. The designer also sets the type of the volume rollof of each source, as it is not necessarily logarithmic, but can be set to linear or custom rollof. After trying different options, in *Soundscaper* we decided to use linear rollof. Although logarithmic rollof would have been more realistic, our tests showed that the linear one gives better overall sound coverage. It is so because the scene contains relatively few sound sources compared to reality. We set the maximum distance to 100m, in order to cover complete simulation area, but to avoid multiple overlapping of sound. Unity audio engine uses binaural mixing console to render the audio. We set the *Spatial Blend* setting of each *AudioSource* to 3D which enabled Unity to automatically blend the sounds taking into account the distance from the listener to the *AudioSource*, and the orientation of the listener. This setting enabled Unity to perform the auralization using inter-aural level difference. When a listener is moving by the *AudioSouce* which is located to its right, the sound coming from the right earphone is louder than the one from the left and vice versa. Although very simple, such simulation gives satisfactory impression of reality as will be shown in the next section.

In Unity, *MainCamera* object provides the user with visual overview of the scene, and the *AudioListener* provides the user with the auralization. We attached the *AudioListener* component to the *MainCamera*, and programmed the *MainCamera* to simulate the real position and the orientation of the user. To do this we used the GPS and magnetometer sensors of the mobile device. Magnetometer sensor provides the real-time data with user orientation, so in our application we just set the orientation of the *MainCamera* object to this value in every frame (typically 30 times per second). On the other hand, the GPS unit on the mobile device does not provide real-time data. It usually gives the fix of the user position every few seconds, which can extend to even half a minute in the case of poor satellite visibility. Changing the position of the *MainCamera* with such low temporal resolution would result with unrealistic and jerky auralization. To overcome this, we used linear interpolation of last two fixes to change the position of the *MainCamera* in every frame. Using this we achieved a smooth auralization, although on the account of accuracy.

We recorded sounds for *AudioSources* in situ, using Tascam DR-100 MK II handheld linear PCM recorder. Sounds were recorded in 24-bit, 44.1kHz, stereo .wav format. Sounds were afterwards edited and normalized in Audacity software. After processing, their length ranged from 55 seconds to 2.5 minutes. In Unity they were attached to *AudioSource* objects, and played in a loop.

The *Soundscaper* application has asplit screen view, with upper half showing the first person view, and the lower half showing the map with the position of the user.



```
FIX:                        INTERPOLATED:
UTMx: 616362m               UTMx: 616352.4m
UTMy: 4818101m              UTMy: 4818115.8m
Time: 102.42s               Time: 103.34s
WindowsEditor               Head:   -23 °
GPS off, stopped.           dT:   4.6s
```

Figure 2. The split screen view of Soundscaper application: first person view (up), and map (down).

The visual part of the *Soundscaper* is used primarily during the design and the tuning of the soundscape. When a user is doing the soundwalk it is of little importance, since the user is supposed not to look at the screen, but to concentrate on the sound.

4. RESULTS

After we had developed the *Soundscaper* application we tested it using the soundwalk method. To establish the reference, we first performed the soundwalk without any AAR equipment (*1-Riva*). These results we then compared with the AAR soundwalk where the soundscape of the Split's Promenade was recreated with the *Soundscaper* (*2-AAR Riva*). Participants were using noise cancelling headphones, which suppressed the real soundscape. To test the performance of noise cancelling, we tested one group by performing the soundwalk with noise cancelling turned on, and without any artificially created soundscape (*3-AAR NC*). The final, fourth test we did to see if an unnatural soundscape would give us different results from the reference and from the recreated one. In this test participants performed the soundwalk with "strange" AAR soundscape. This soundscape covered the same area of the Split's promenade, but with "out of the place" sounds of construction sites, heavy traffic and factory machines (*4-AAR street*).

Figure 3. The participant performing the soundwalk with AAR equipment.

The soundwalk was performed using Samsung Galaxy S7 mobile phone, and Bose QuietComfort 25 noise cancelling headphones (figure 3). After short introduction, the participants performed the soundwalk in the duration of approximately 10 minutes, and then entered the questionnaire.

Table 1. Questions were divided into three groups: general, spatial/temporal and *emotional impact*.

1. Quiet/ Loud	**4.** Harmonious/ Disharmonious	**7.** Not Present/ Present Everywhere	**10.** Directional/ Universal	**13.** Steady/ Unsteady	**16.** *Calming/ Agitating*
2. Unclear/ Distinct	**5.** Meaningful/ Insignificant	**8.** Nearby/ Far	**11.** Fit/ Strange	**14.** *Lively/ Boring*	**17.** *Social/ Unsocial*
3. Natural/ Artificial	**6.** Deep/ Shrill	**9.** Reverberant/ Anechoic	**12.** Organized/ Disorganized	**15.** *Pleasant/ Unpleasant*	

Questionnaire consisted of 17 questions that the participants answered on a 7-point Likert-Type scale. Questions covered three dimensions of impressions: general characteristics of the soundscape, spatial and temporal characteristics and emotional impact on listener. At the end of the questionnaire the participants could write additional comments and observations, not covered with the questionnaire.

Each participant performed at least two soundwalks: the first, reference *1-Riva* soundwalk, and one of soundwalks with AAR equipment. The participants were of both sexes, aged between 15 and 45 years, mostly students and IT professionals. They performed a total of 55 soundwalks. The results are shown in table 2, with soundwalks presented in rows, and questions in columns. For each soundwalk we presented the average answer (*AVG*), with Likert scores from -3 to 3 and the standard deviation of answers (*STD*). For AAR soundwalks we presented an additional row (*DIFF*), with the absolute value of the difference of the average answer, between the AAR soundwalk and the referent *1-Riva* soundwalk. The smaller this difference was, the more similar the soundwalk was to the referent one.

Table 2. Results of soundwalks.

No.		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**AVG**
1-Riva	AVG	1,50	-0,36	-1,64	-0,29	-0,57	0,21	1,86	-0,79	0,21	-0,21	-1,57	2,36	-1,07	-1,07	-0,93	-0,07	-2,29	
	STD	0,94	1,28	1,65	1,68	1,91	1,31	0,77	1,37	1,76	1,72	1,40	0,93	1,86	1,59	1,14	1,21	0,83	**1,37**
2-AAR Riva	AVG	1,29	-0,29	-1,57	-0,36	-1,43	0,36	1,29	-0,71	-0,36	-0,21	-1,86	1,21	0,14	-1,29	-0,86	-0,14	-1,57	
	STD	1,44	1,86	1,28	1,39	1,28	1,28	1,20	1,49	1,55	1,67	1,03	1,37	2,11	1,49	1,41	1,79	1,55	**1,48**
	DIFF	***0,21***	***0,07***	***0,07***	***0,07***	***0,86***	***0,14***	***0,57***	***0,07***	***0,57***	***0,00***	***0,29***	***1,14***	***1,21***	***0,21***	***0,07***	***0,07***	***0,71***	***0,37***
3-AAR NC	AVG	-2,14	-1,29	-0,93	-0,50	1,14	-1,00	1,29	0,79	2,00	0,79	-1,43	1,07	0,21	0,71	-0,36	-1,00	0,79	
	STD	0,86	1,77	1,77	1,51	1,66	2,32	1,54	2,01	1,36	2,15	1,45	1,59	2,04	2,30	1,95	1,75	2,39	**1,79**
	DIFF	***3,64***	***0,93***	***0,71***	***0,21***	***1,71***	***1,21***	***0,57***	***1,57***	***1,79***	***1,00***	***0,14***	***1,29***	***1,29***	***1,79***	***0,57***	***0,93***	***3,07***	***1,32***
4-AAR street	AVG	1,62	-0,38	0,23	-0,62	-0,15	0,31	1,54	-0,15	-0,38	0,08	2,23	0,23	-0,15	0,38	1,62	1,38	1,54	
	STD	1,76	2,02	1,88	1,89	2,34	2,02	1,33	1,82	1,50	2,10	1,17	2,01	1,46	1,80	1,66	1,66	1,33	**1,75**
	DIFF	***0,12***	***0,03***	***1,87***	***0,33***	***0,42***	***0,09***	***0,32***	***0,63***	***0,60***	***0,29***	***3,80***	***2,13***	***0,92***	***1,46***	***2,54***	***1,46***	***3,82***	***1,22***

In figure 4 we graphically showed the answer difference, as the measure of similarity between the AAR soundwalk and the referent one. Left chart presents the difference for *2-AAR Riva* soundwalk (presented with solid line), and for *3-AAR NC* soundwalk (dashed line). The difference for *2-AAR Riva* is evidently smaller than for *3-AAR NC*, with the average difference of 0,37 for *2-AAR Riva*, against 1,32 for *3-AAR NC*. Right chart compares the difference for *2-AAR Riva* soundwalk, with one for *4-AAR street* soundwalk (dotted line). As in the left chart, the difference for *2-AAR Riva* is visibly smaller than the other one, with the average difference of 0,37 for *2-AAR Riva*, against 1,22 for *4-AAR street*.

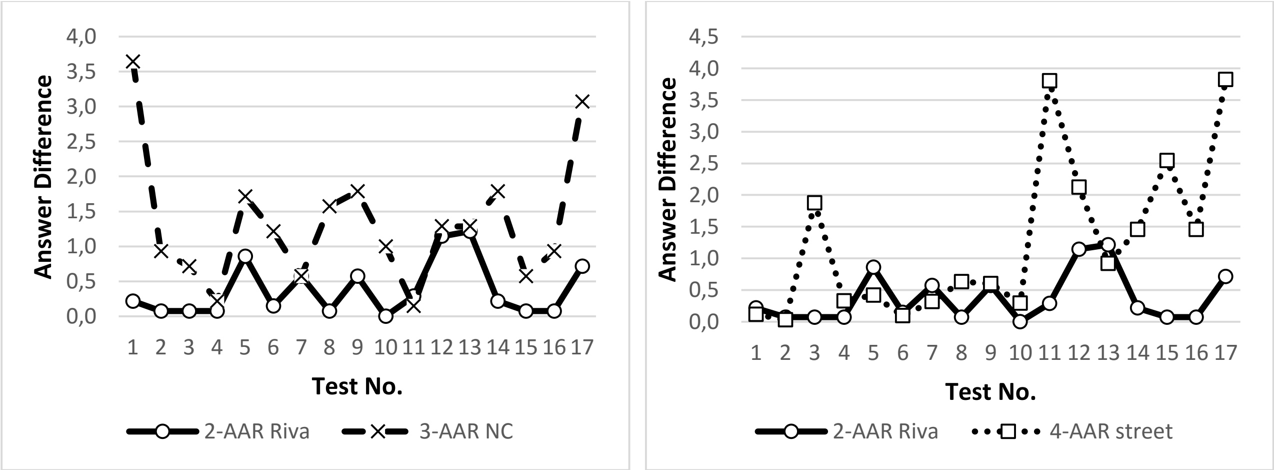


Figure 4. Comparison of difference in participants answers between reference and AAR soundwalks.

From these results it is clear that the AAR soundscape of Riva is very similar to the real soundscape, which means that our *Soundscape* application can realistically perform an auralization of a soundscape. This conclusion is supported with the results of the auralization of a busy street. In this case the results differ from the referent soundwalk, although the soundwalk was performed in the same area. This proves that our application can create the targeted sonic impression, even if it is not backed up with visual clues of the surrounding area. Also, the results show that noise cancelling equipment we used in our tests works well, because participants' answers in this case significantly differed from the referent soundwalk.

5. CONCLUSIONS

In this paper we presented the beginning of our research of soundscape auralization of ancient archaeological sites – the development of the mobile AAR application for soundscape auralization named *Soundscaper*. Using this location-aware application, people can experience the auralized soundscape using headphones. The application was tested using the soundwalk method on Split's promenade. The results of the first test, a soundwalk of the real soundscape, without AAR equipment were compared to three tests performed with *Soundscaper* and AAR equipment.

The results of recreated AAR soundwalk of original scene resembled the real, referent soundwalk. On the other hand, results of AAR soundwalk of a busy street and one performed with noise cancelling equipment, differed significantly from the referent soundwalk. This proved that our soundscape auralization performs well, and that it could be used for auralization of ancient soundscapes in archaeological sites.

In the future we plan to recreate the ancient soundscape of Salona, the metropolis of the Roman province of Dalmatia, using AR glasses instead of the mobile phone and headphones. We plan to test the recreated soundscape against the existing real one on the tourist population, to gain insight of the usefulness of such approach.

ACKNOWLEDGMENTS

This work has been supported in part by the Croatian Science Foundation under the project number UIP-2014-09-3875.

6. REFERENCES

[1] Botteldooren, Dick et al., "Understanding Urban and Natural Soundscapes", Proceedings of the Forum Acusticum, Aalborg, 2011, pp. 2047–2052.

[2] Bruce N.S., Davies W.J., "Development of a soundscape simulator tool", Proceedings of Internoise 2009, Ottawa, 23.-29.8. 2009.

[3] Harriet S., Murphy D.T., "Auralisation of an Urban Soundscape", Acta Acustica united with Acustica, Vol. 101, 2015., pp. 798 – 810

[4] Guastavino C. et al, "Ecological Validity of Soundscape Reproduction", Acta Acustica united with Acustica, Vol. 91, 2005., pp. 333 – 341

[5] Kinayouglu G., "Using Audio-Augmented Reality to Acess the Role of Soundscape in Environmental Perception", Proceedings of conference on education and research in computer aided architectural design in Europe, Istanbul, 16.-19.9. 2009.

[6] Vorlander M., "Auralization", Springer, Berlin, 2008.