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STUDYING OUTDOOR IMPULSE RESPONSES AT IHTA PARK: SIMULATED VS. MEASURED

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ABSTRACT

Today, there is a lack of standardized methods to study people's perception of the architectural design of urban spaces. Moreover, outdoor spaces are subject to a continuous change of environmental conditions and variability of possible scenes. In order to conduct sensory evaluation experiments under reproducible conditions, it has been proposed to use virtual audio-visual models. One such model is the recently published digital twin of a green space in Aachen, named IHTApark. Its visual appearance is derived from a photogrammetry, followed by an implementation and rendering in Unreal Engine. For audio reproduction, the game engine is connected to the open-source software Virtual Acoustics. This allows to include fully synthesized sound sources as well as transfer paths both rendered in real-time or pre-rendered. This contribution compares measured with simulated impulse responses (IRs) of IHTApark. The simulated IRs are computed using geometrical acoustics while the measured IRs are obtained by sweep measurements. The measurements will be used to fit and validate the simulation results.

Keywords: *Outdoor, Impulse Responses, Auralization, Measurement*

1. INTRODUCTION

The urban environment named IHTApark is the digital twin of a green space in Aachen. It has been proposed to conduct audio-visual experiments under reproducible conditions, i.e. in a virtual environment [1]. In this virtual environment, auditory stimuli can be simulated and reproduced by the open-source software Virtual Acoustics [1], while its visual appearance, which has been derived from a photogrammetry, is implemented and rendered in Unreal Engine [2, 3]. Virtual Acoustics allows to account for fully synthesized or recorded sound sources, both rendered in real-time or pre-rendered, as well as for various playback methods.

The focus of this paper lies on the sound propagation paths which determine the filters between source signal and receiver. In the field of room acoustics, geometrical acoustics has shown good performance to simulate transfer functions that represent the actual propagation paths well, cf. [4–6]. At the same time, these methods allow for obtaining results in or close to real-time [7]. Therefore, we suggest to study their application in the field of outdoor acoustics.

The target scenario for this study is the design of a plausible, complex scenario to auralize car pass-by, cf. [8]. While we propose to use calibrated background recordings to enhance the overall plausibility of the virtual experience [9], we aim at better understanding the propagation paths from relevant sources, i.e. cars, to receivers in the study environment.

2. METHODOLOGY

In the presented first approach, the authors have decided on one source (S) and five receiver positions (R1-R5) to

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[1] www.virtualacoustics.org

study their corresponding impulse responses (IRs). The positions are depicted in Fig. 1. In the following, we will focus on R1 only. It has a distance of S-R1 = 58.4 m to the source.

2.1 Simulation

The simulations are based on geometrical acoustics, more specifically, the software Raven [2]. It is based on the image source model (in this case of third order) for early reflections and ray tracing for later reverberation (here: 30 Mio. particles). It allows to apply random-incidence absorption and scattering coefficients to the polygons of the geometry mesh. The IR is generated by superposition of all detected paths.

The 3D model of reduced complexity for the acoustic simulation (see Fig. 1) has been drawn on top of the cadastral plan and with the help of the visual model for reference. It has 202 polygons and eight groups of surface materials (= eight colors) assigned. The absorption and scattering coefficients which have been applied to the eight materials are shown in Fig. 2.

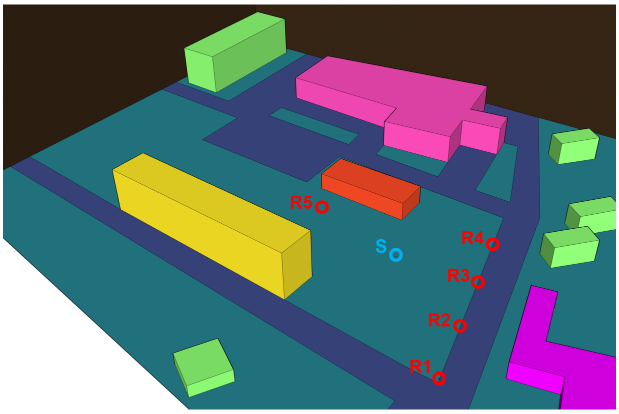
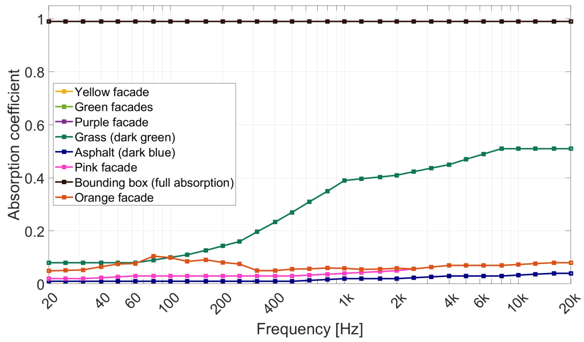


Figure 1: Simplified virtual 3D model of the study environment *IHTApark* for simulations applying geometrical acoustics.

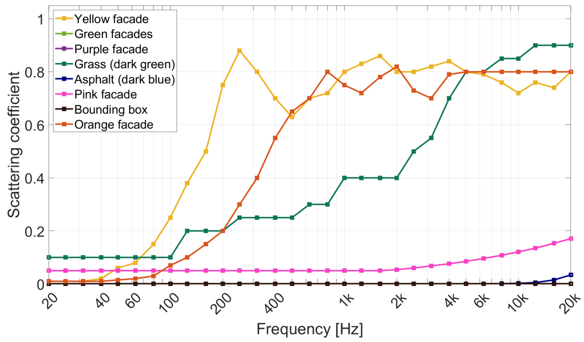
2.2 Measurements

The transfer functions have been measured using the swept-sine method described by Müller and Massarani [10]. The sweeps were reproduced with a three-way

[2] www.virtualacoustics.org/RAVEN/



(a) Absorption coefficients



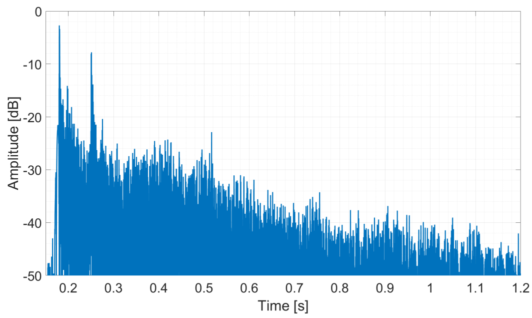
(b) Scattering coefficients

Figure 2: Frequency-dependent material properties for the IR simulation. The corresponding surfaces can be located in Fig. 1.

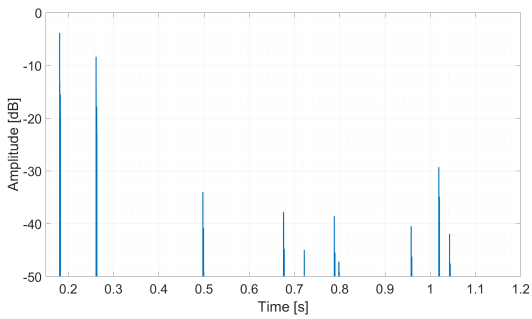
dodecahedron loudspeaker introduced by Behler and Vorländer [11] and recorded with an omnidirectional microphone. The loudspeaker system applies an FIR-filter equalization and shows an omnidirectional sound radiation up to 6 kHz. In the measurement setup, the radiating port is at 106 cm above ground for the subwoofer, 136 cm for the mid-range unit and 165 cm for the high-frequency dodecahedron. The recording positions are consistent with the ones shown in Fig. 1. The height of the microphone is always 1.2m above ground.

3. RESULTS & DISCUSSION

This section gives preliminary results of both the measured and the simulated IR for position R1. They are plotted in Fig. 3. The IRs' amplitudes are normalized to match in their first maximum. This first maximum represents the direct sound that arrives at the receiver from the source after traveling the shortest possible path. The second maximum represents the most important first reflection which appears in this case at the facade of the purple building, see lower right corner in Fig. 1. This meets well the expectations since the time difference (Measurement: 0.07 s, Simulation: 0.08 s) between both peaks fits well with the additional distance the sound travels across the street. The small deviations could occur due to small inaccuracies in the modeling, sound source and receiver positioning or inhomogeneity in the atmosphere.



(a) Measurement



(b) Simulation

Figure 3: Impulse response from source S to receiver R1 (normalized to amplitude at first peak).

The broadband difference in amplitude between the two first maxima is 5 dB for the measurement, and 4.5 dB for the simulation. After the direct sound (between first and second maximum), we can observe bottom reflections. While they are clearly visible for the measurement in Fig. 3, they appear to be significantly lower in level for this preliminary simulation. While the global structure of the IRs match well with regard to the main peaks, the fine structure and frequency dependency should be studied in more detail.

In general, the simulation shows almost no energy content between distinct peaks. This can be expected when only few mesh polygons are involved in the propagation path. Thus, only distinct reflections arrive at the receiver. Particularly, when inspecting the measurements, we recognize more energy content between the first peaks. Since no facade is close enough to play a role here, we would expect more influence from the ground on the early part of the IR than the simulation accounts for.

4. OUTLOOK

The first results show that the direct sound and the first reflection at facades are well represented by the image source model. But in reality, the bottom reflection including the ground effect and the later reflection pattern have a more complex structure, cf. [12]. Therefore, one future task is to find a simulation setup that improves these parts. This might also include remodeling the ground to enable the algorithms to better predict ground reflections and other effects, e.g. diffusion due to smaller objects. One approach could be to vary the sparsity of the mesh.

The measurement is regarded as the reference for this comparison study. Nevertheless, the uncertainties of the measurement are worth being investigated. It is planned to perform another measurement with another source with well described directivity as well as various source and receiver positions which represent better the whole area. This would also allow us to study other simulation tools which account for diffraction.

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