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BRINGING SOUNDSCAPE AURALIZATIONS TO THE URBAN CITY PLANNING

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ABSTRACT

The use of city-scale big data in urban planning practices has grown significantly over the past few decades, revolutionizing the way cities are designed and managed. This trend holds the promise of creating urban environments that better account for the perceptions, needs, and complex interactions of people with the built environment. However, despite these advancements, there remains a lack of comprehensive frameworks for incorporating the auralization of urban soundscapes into city-scale big data systems. The integration of soundscape auralization is critical, as it offers the potential to address the acoustic dimension of urban life, enabling more informed and human-centered urban sound planning. In this regard, soundscape auralization frameworks are expected to play a pivotal role in facilitating data-driven decision-making processes that enhance the auditory quality of urban spaces. This contribution aims to address the challenges associated with achieving such integration, outlining a structured workflow for creating soundscape digital twins—virtual representations of urban acoustic environments. The contribution will also highlight that these digital twins could serve as powerful tools for simulating and evaluating soundscapes, ultimately supporting urban planners in designing cities that are not only functional but also acoustically pleasant.

Keywords: *soundscape, auralization, urban, acoustics.*

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1. INTRODUCTION AND SIMULATION WORKFLOW

As urban challenges become more complex, innovation alone is insufficient; strong partners are needed for comprehensive support and diverse perspectives. The Fraunhofer Institute for Building Physics in Stuttgart has established the Urban and Architectural Acoustics research group (UAA) to accelerate innovation in urban acoustic challenges. By uniting research institutions and demonstration environments under one partner, it aims to improve solutions for society's sound and noise issues.
Noise mapping is a well-established practice in acoustic urban planning, calculating noise levels based on sound source models, propagation effects, and receiver positions. However, this method is limited to frequency band levels, lacking temporal and spectral information, which affects qualitative sound properties evaluated through psychoacoustic parameters. Auralization and physically-based simulation can enhance urban soundscape analysis beyond classical noise mapping. By integrating auralization technology with visual representations of urban spaces, a plausible virtual environment can be created. In this chapter we present the simulation workflow used by the UAA group and in chapter 2 we discuss several challenges and opportunities of soundscape auralizations in urban planning.

1.1 Auralization signal chain

An auralization usually consists of separated simulation models for sources, propagation, and receivers [1]. Virtual Acoustics (VA) is a physics-based auralization framework developed at the Institute for Hearing Technology and Acoustics (IHTA) at the RWTH Aachen university [2] and is intended to be used by the UAA group.

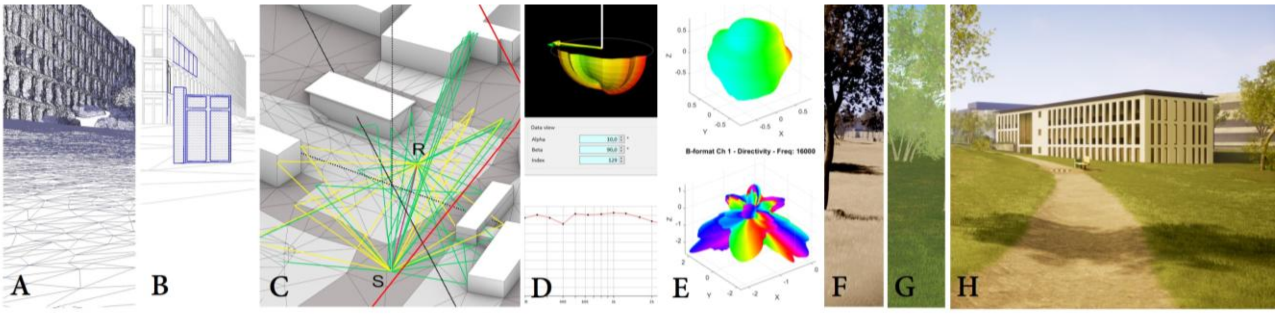

Figure 1. Soundscape auralization workflow example: A) photogrammetry; B) visual geometry; C) acoustic geometry and sound propagation paths; D) sound source directivity characterization; E) 1st HOA receiver characterization; F) light sources and shadows calculation; G) visual materials definition; H) Final audio-visual model of IHTApark [5].

In general, VA allows the acoustic rendering of virtual scenes purely based on synthesized data using physics-based models. It follows a server-client architecture with bindings to various technologies like Matlab (The MathWorks, Portola Valley, CA), Python (Python Software Foundation, Wilmington, DE), Unity (Unity Technologies, San Francisco, CA), or Unreal Engine (UE). Using a purpose-built plugin, UE connects to an instance of VA. During execution, all sound source information is forwarded. VA then handles the auralization including propagation effects according to the selected renderers, as well as the reproduction via an audio interface (Figure 1).

The sound propagation model applies effects to the raw input signal from the source model. For outdoor auralization, it involves two steps: simulating geometric sound paths connecting source and receiver, and deriving acoustic parameters for each path, including spreading loss, propagation delay, and air attenuation. These parameters, called auralization parameters, control digital signal processing during auralization. The consideration of propagation effects and sound path simulation depends on the detail level needed for the scenario. For a car pass-by in an open field, considering solely direct sound and ground reflection may suffice, while urban scenarios require additional effects like reflections and scattering, especially in dynamic situations where movement can occlude direct sound.

1.2 Visualization framework

The basic paradigm of visual simulation of architectural and urban scenes includes four interconnected prerequisites: geometry, materials, light sources and viewers. The approach to construct the model is highly modular. The modular setup allows for the independent modification of each module under certain variables, independent from the rest of the modules, which makes the models versatile. The visualization includes the following elements: geometry, or ways to represent and process surfaces; an imaging or processing acquisition, ways to reproduce the visual—or material—characteristics of objects; rendering, algorithms to reproduce light rays; and animation, ways to represent and manipulate motion, as described by Foley et al. [4]. Further details on the visualization workflow can be found under Llorca-Bofí et al [5].

1.3 Digital twin scenario for validation

To test and develop the simulation workflow, an immersive environment was created over the last years. The IHTApark digital twin, an accurate virtual recreation of the small park behind IHTA in RWTH Aachen, was chosen for this purpose. Combined with VA and the UE VA plugin, the IHTApark project serves as a template for complex audiovisual environments [5]. The park was monitored with audio recordings across multiple weather conditions and visually recreated in Unreal Engine (UE) for presentation on monitors and in VR. The templates made use of VA for auralization and simulated sound propagation in IHTApark with a simplified acoustic model. Further validation of these urban digital twins is planned by the UAA group soon.

2. SELECTED CHALLENGES AND OPPORTUNITIES

2.1 Weather changes

One major problem in auralizing complex urban scenarios is creating ambience - the diffuse background representing the sound floor for the acoustic scene. Omitting realistic ambience leads to a sterile impression. A hybrid approach with spatially recorded background sounds appears promising. Llorca-Bofí et al. [6] explored the influence of weather changes on psychoacoustic parameters (Figure 2). To address improving spatial diffusivity and accounting for weather-dependent variations in outdoor auralizations, we collected and characterized background sounds from the urban scenario IHTApark regarding acoustic parameters and weather conditions. Results indicate that sharpness and roughness correlate highly with relative humidity and cloudiness, while tonality relates to surface wetness. In contrast, loudness correlates with fewer and weaker weather indicators. Thus, it is important to use background sounds in virtual soundscapes, given that the temporal and spectral content affect the soundscape evaluation as well.

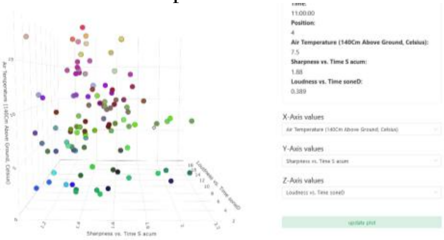

Figure 2. A web application to explore a dataset of ambient noise recordings made at IHTA Park. It can be interactively explored here: https://paad-group.github.io/IHTApark-ambient-recordings/

2.2 Auralization for citizen science

The use of such digital twins in citizen science is a promising field. They can be used to collect assessments of urban design variations across questionnaires to citizens using streaming technologies. In [2] the authors validated the plausibility of such tests comparing virtual reality and web-based listening experiments. For such noise perception experiments, the results are promising, showing minimal differences in questionnaire ratings between VR and streaming reproduction. Visual quality ratings suffered mildly in the consumer setup, but auralization quality was rated similarly positive in both cases. Even for lower feeling of presence in the consumer setup, the subjects' attention remained similarly high despite having lower sense of presence in the consumer setup. Finally, accessibility and quality ratings indicate equally promising results.

2.3 Neural networks training of urban soundscapes

Recent advances in machine learning (ML) and artificial intelligence (AI) have enabled predictive models that capture nonlinear interactions between environmental parameters and psychoacoustic features. Specifically, neural networks are powerful tools for modeling these complex relationships. The authors explored the performance of Back-Propagation networks in predicting psychoacoustic features from urban meteorological inputs using a soundscape database as training data (Figure 3) [7]. The networks' predictive potential suggests that synthetic soundscapes could be generated for various urban situations. These synthetic soundscapes could preserve the physical and psychoacoustic properties from the training data while streamlining the time-consuming modeling process of soundscape environments.

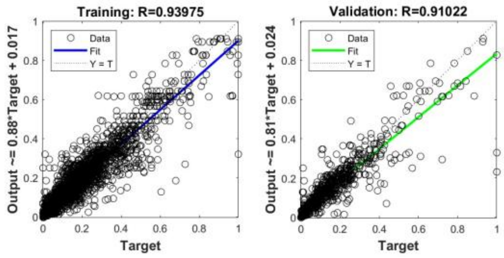

Figure 3. Back-propagation network performance prediction of psychoacoustic indicators based on weather indicators. The dataset is part of the urban background soundscapes dataset, using 80 % as training data and the resting 20% as validation dataset.

2.4 Integrating sustainability measures with noise simulations in urban planning

Towns and cities have to strike a balance between the needs of society and individuals, which tend to clash and coincide with one another. Acoustic urban design has to deal with an unrestrained demand for mobility, increasing urban density and many other factors, together with all other sustainable challenges that cities face. For this reason, today it is even more important to look at the future of acoustic urban design integrated to sustainability measures. The integration of acoustic data together with sustainability data in urban planning simulation is key to tackle those challenges. Available acoustic measurements, air pollution reduction index, resilience to climate change and other data for green facades at the Fraunhofer-IBP makes the urban planning simulations and optimizations possible (Figure 4).

Figure 4. Measurements of the integrated database of acoustic and other sustainability indicators, available at https://imcom2.hoki.ibp.fraunhofer.de/attribute/index.php

2.5 Soundscape planning at the micro, meso and macro levels

Figure 5. Urban planning concept fort he „Gräselberg – Auf den Eichen“ urbanization area, in Germany, by Reicher-Haase Assoziierte.

The use of auralization techniques might be implemented at different scales in the urban design process, this is for example, to check the impact of the U-shaped buildings as sound barriers for the highway noise, or to assess the impact of the façade manterials to reduce noise on the inner courtyards (See Figure 5). However, since auralization techniques aim to render the soundscape at the receiver position, it is important to mention that the renderings will be perceived from the human point of view, this is, as a pedestrian or dwelling inhabitant. In order to assess the impact of the near sounds as well as the far-away ones, the physically-based auralization techniques previously presented are necessary.

3. DISCUSSION AND CONCLUSION

In this manuscript a workflow to integrate soundscape auralization in urban planning was presented and selected challenges were discussed, in particular, the effects of varying weather conditions, the opportunities of urban soundscape auralization for citizen science, the use of neural networks to agilize the simulation processes, and the integration of sustainable data of facades and buildings, into the acoustic simulations to achieve a multidisciplinary urban planning. Further work at the UAA group will be published in future steps.

4. ACKNOWLEDGMENTS

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