An Acoustically Optimised Garden Fountain to improve Soundscape Quality in Domestic Environments

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Introduction

Unwanted sounds and noise can have a negative impact on human health and quality of life, particularly in the domestic environment, being a sensitive space of retreat. For example, a German study found results supporting the hypothesis that stress resulting from constant exposure to road traffic noise can increase the risk of ischaemic heart diseases like myocardial infarct [1].

Sometimes noise reduction at the source is not possible or does not yield the desired effect. Legally prescribed exposure limits for residential areas exist, but even if these are met, the noise can still be perceived as annoying and therefore impose stress on residents. In that case, the introduction of a pleasant sound into the noisy environment offers an alternative to improve the overall pleasantness of the acoustical environment. In a questionnaire survey by Guastavino [2] on the sound quality of French cities, natural sounds like wind and water were described as positive parts of the urban soundscape by the participants. Of those natural sounds, water sounds are already widely used by city planners in the form of fountains to enhance the recreational function of city parks and public gardens. Thus, for domestic environments affected by traffic noise, small water features like garden fountains could be used to improve the environment's pleasantness.

The applicability of water sounds for soundscape enhancement has been shown in laboratory experiments before [3, 4, 5, 6]. However, these findings are constrained to the controlled conditions under which the respective studies were conducted. Real domestic environments further include a variety of influential factors and the findings gathered in the laboratory have to be validated in this different context. Saegert [7] calls dwelling the "most intimate relationship with the environment". It can be expected that humans react differently to noise in their respective homes than in other places to which they do not have such a strong emotional connection. Moreover, field studies can reveal possible long-term effects that cannot be observed in short-term laboratory experiments.

To assess the applicability of water sounds for improving soundscape quality under real-life conditions, we constructed an acoustically optimised garden fountain. The fountain was designed to achieve an acoustical characteristic similar to a small stream, which was preferred in listening experiments [5]. With its use in a field study in mind, we also aimed for easy handling and setup of the fountain. This paper focusses on the design process and the characteristics of the garden fountain.

Pleasant Water Sounds

A sound's potential for improving the overall pleasantness of an acoustical environment depends on its own pleasantness. Rådsten-Ekman et al. [4] reported that highly pleasant water sounds may increase the pleasantness of the whole acoustical environment. On the other hand, adding less pleasant sounds to the environment may have no effect on the overall pleasantness or even degrade it. Therefore, only highly pleasant water sounds should be considered for soundscape enhancement.

The subjective response to water sounds in combination with traffic noise is influenced by the type of the water sounds and their spectral characteristics. Traffic noise generally consists of a higher amount of low-frequency content. A water sound therefore has to contain more or similar amounts of energy at low frequencies to mask traffic noise in a sufficient way. Watts et al. [8] investigated the masking effects of different kinds of water sounds. The sounds were generated by varying the impact medium of the falling water which resulted in different spectral properties of the sounds. Hard surfaces produced the highest frequencies while lower frequencies were generated by water falling on water or into cavities. Compared to traffic noise, the generated water sounds had less spectral energy at frequencies below 1kHz and more spectral energy at higher frequencies. Therefore, water sounds produced by small water features do not provide sufficient masking potential for traffic noise. Conversely, in a subsequent listening test, the tranquillity of an acoustical environment containing traffic noise could be improved by adding water sounds. This indicates that masking is not a crucial factor for soundscape enhancement with water sounds. It is more likely that the introduced water sounds draw the listener's attention away from the unpleasant noise. This, in turn, improves the overall perceived pleasantness of the acoustical environment.

Galbrun and Ali [5] drew similar conclusions. They examined acoustical and perceptual properties of different water sounds for the application of road traffic noise masking. Different kinds of water features (waterfalls, fountains, streams, jets) were used for sound generation and the influence of the flow rate, the falling height, the edge design and the impact medium was investigated.

Most water features could not generate low-frequency sounds in an extent to sufficiently mask road traffic noise. The authors also investigated participants' preferences for different kind of water sounds and found that streams were preferred to waterfalls and fountains. However, streams with lower sharpness were associated with artificial sounds – like water falling into a drain – and were not liked. This is in line with findings of Jeon et al. [9]. They determined sharpness as a dominant factor for the subjective response to water sounds in urban spaces. Higher sharpness resulted in higher preference scores of the acoustical environment and also increased the perceived freshness of the environment.

The temporal variability of a water sound also affects the subjective response. Watts et al. [8] found that natural sounds that include temporal variations were best suited to enhance the tranquillity of an acoustical environment.

Based on these findings, we concluded that a garden fountain should have acoustical characteristics similar to a small stream or creek, in order to enhance the soundscape in domestic environments. The sound should contain more high- than low-frequency energy to achieve a high sharpness. Container resonances or similar tonal sounds that could be associated with artificial structures like drains or barrels should not occur. In addition, a variable water sound should be perceived as natural and thus more pleasant.

Design choices of the fountain

To achieve the acoustical characteristics of a small creek, we built the fountain as a water cascade system with multiple outlets (figure 1). The fountain consists of three containers stacked into each other and two additional small containers with water slides. Internally mounted tubes lead the water from the pump, which is located in the bottom container, up to the top container. During setup, the containers are easily connected by closing screw connections. A valve is mounted at the outlet of the pump tube in the top container to allow for adjustments of the flow rate.

We chose water as the impact medium of the cascades since this configuration was preferred in listening experiments [5]. In contrast to harder impact media, water emits more mid- and low-frequency sounds which are mainly produced by bubbles of air being pulled underwater below the cascades. When rising from the water, the bubbles vibrate and emit sound waves [8]. To lessen the amount of air being pulled underwater, the falling height was limited to 10cm (figure 1, top left). This height yielded optimal results and was determined in a series of experiments. For higher falling heights, more unpleasant low-frequency sounds occur and the cascades tend to converge to narrow jets of water. The narrower the cascade is on impact, the more it produces unwanted tonal sounds. Reducing the falling height yields the drawback of also reducing the overall sound pressure level of the fountain. This was compensated by increasing the number of cascades. Doubling the number of cascades or their width, respectively, leads to an increase of 3dB in sound pressure level [5].

Figure 1: The garden fountain

Since the pump is located in the bottom container, the middle container had to be placed on long stilts. To still achieve a falling height of 10cm for the cascades, two smaller containers were added right under the outlets of the middle container. Sieves placed inside the containers just below water level reduce the amount of air bubbles pulled underwater by the cascades (figure 1, bottom right).

To further broaden the cascades, we applied sawtooth edges made of multiple layers of aluminium tape at the outlets (figure 1, top left). This was already evaluated by Galbrun and Ali [5] who found this configuration to be more liked than having the water flow from a plain edge. We used this approach differently here, though, since in our fountain the water completely overflows the sawtooth edges. The edges shape the outflowing water into a broad, consistent cascade and prevent it from breaking up into several small jets.

A steady shape of the cascades is important for achieving a stream-like sound. To achieve this, a high water flow rate and an even water surface in the container from which the cascades emerge are needed. The water flow rate can be adjusted by opening or closing the valve in the top container. However, for higher flow rates, the water pushed up by the pump disturbs the water surface in the top container (figure 1, top right). Cascade shapes change erratically and create irritating splashing sounds. Air bubbles get trapped in the moving water surface and additionally produce unwanted sounds. We suppressed these disturbances in the top container by placing a wooden slab over the pump outlet. The water's kinetic energy is redirected by the wood and the water surface remains calm and even (figure 1, top).

Characteristics of the fountain

To assess the fountain in terms of acoustical and psychoacoustical metrics, we recorded the fountain sound in a controlled environment. We set up the fountain in an acoustically treated and insulated listening room which is usually used for listening experiments. An artificial head microphone (HEAD Acoustics HMS II.3) was used for the recording. The distance between the artificial head and the fountain was 1m with an ear height of 1.6m.

The fountain has a steady, homogeneous sound without major level fluctuations. Temporal variations occur on a smaller scale, though, producing a lively and natural water sound, as can be seen in the spectrogram (figure 2). Overall, the fountain produces an A-weighted sound pressure level of $L = 48.3\text{dB}_\text{A}$. The spectrum of the water sound is dominated by mid- and high-frequency components (figure 3, orange). Most of the spectral energy is contained in frequencies above 1kHz. This results in a high sharpness value of 3.1acum[1].

During operation, the pump emits a low-frequency humming sound composed of 50Hz harmonics. In an everyday sound environment, the pump noise is not audible in a distance of approximately 1m from the fountain. However, in the measurement room, the pump noise is much more present, as there is no masking due to low-frequency noise. To capture the fountain's characteristics without the influence of the pump, the fountain was recorded in two configurations: normal operation with the pump running (configuration A) and with the pump switched off and water being poured manually into the top container using a watering can (configuration B). This way, in configuration B, a similar flow rate as in configuration A was achieved.

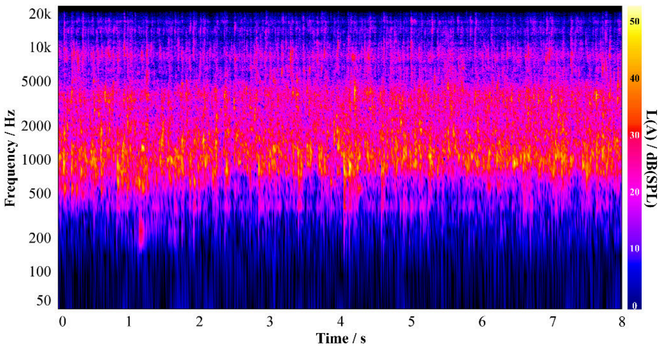

Figure 2: A-weighted Spectrogram of the fountain sound recording (configuration B). Small-scale temporal variations occur, while the overall characteristic does not change.

Figure 3 shows the A-weighted spectra of the two configurations in comparison. The influence of the pump noise is clearly visible as peaks in the spectrum at whole multiples of 50Hz. At frequencies above 1kHz, the water sounds dominate the fountain sound in both configurations.

[1]Computed using the method proposed by Aures [10]

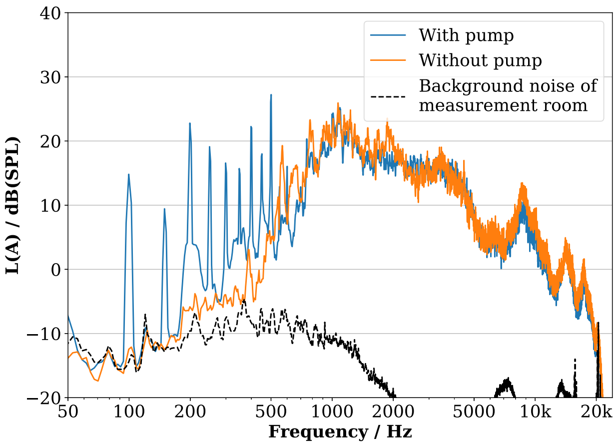

Figure 3: A-weighted Spectra of the fountain recordings

Field Study and Future Research

In a previous laboratory experiment, the fountain positively influenced the pleasantness ratings of an auditory scene affected by traffic noise [3]. However, possible effects that take a longer time to set in could not be observed due to the short duration of a laboratory study. And although the testing environment was designed to resemble a garden, the findings are not necessarily transferable to the different context of real domestic environments. Since people usually have an emotional connection to their homes, it can be expected that they respond differently to traffic noise and added water sounds there than in a laboratory environment. Therefore, we conducted an exploratory field study in a residential area near a highway to assess the fountain under real-life conditions. Despite of a noise protection barrier that was constructed next to the highway, most of the people living in the settlement report being disturbed or annoyed by road traffic noise.

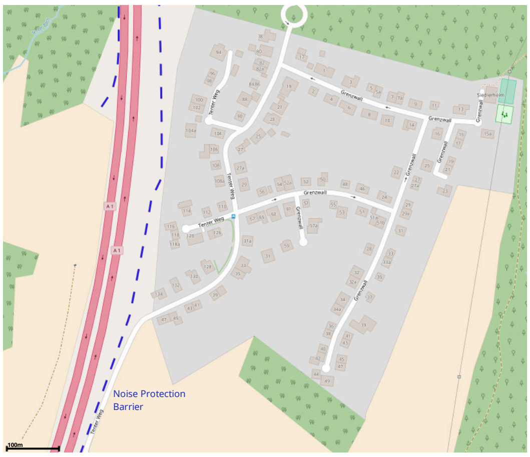

Figure 4: Field study location. Noise protection barriers are denoted in blue.

Four identical fountains were set up in four gardens for a period of two months. Over the course of the study, the subjects repeatedly rated the pleasantness of the acoustical environment in their garden. Additionally, the