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Research Paper

A case study on controlling sound fields in a courtyard by landscape designs

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HIGHLIGHTS

- Examined the acoustic effects of landscape designs in a courtyard.
- Measurements show that a practical landscape design reduces sound levels by 3.1 dB.
- Computer simulation shows that vegetation can reduce speech levels by 10.7 dBA.
- It is found that vegetation is effective in reducing reverberation time by 82% at 500 Hz.

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ABSTRACT

Courtyards surrounded by buildings often have acoustic defects such as strong flutter echoes and long reverberation time (RT) that can increase noise annoyance. Therefore, it is important to absorb and diffuse sound energy propagating such places. The aim of this paper is to investigate how applicable landscape designs can contribute to controlling sound fields in a courtyard, with particular attention to the acoustic effects of vegetation. Through a case study, differences between courtyard sound fields were examined by in situ measurements before and after applying a practical landscape design using vegetation, wood decking and street furniture. In addition, computer simulations were carried out to explore the acoustic effects of applicable landscape designs using vegetation including climbing Ivy, green wall, grass and bedding plants. The results for the in situ measurements showed reductions in sound levels and RT20 at 500 Hz of 3.1 dB and 40% (1.0 s), respectively. The results for the computer simulation showed that the green wall on the façade can reduce speech levels and RT20 at 500 Hz by 9.3 dBA and 81% (2.1 s), respectively. The bedding plants on the ground decreased the speech level by 2.2 dBA and increased RT at 500 Hz by 12% (0.3 s). At different floor levels in the accommodation building, the speech level and RT20 at 500 Hz were decreased by the vegetation by up to 5.5 dBA and 66% (1.1 s), respectively.

1. Introduction

A growing body of evidence confirms that urban noise pollution produces direct and cumulative adverse health effects such as cardiovascular disease, cognitive impairment, sleep disturbance, tinnitus and annoyance (Fritschi, Brown, Kim, Schwela, & Kephalopolous, 2011). These health effects, in turn, can lead to social handicap, reduced productivity, decreased performance in learning, absenteeism in the workplace and school, increased drug use and accidents (Berglund, Lindvall, & Schwela, 1999). Noise could also have economic impacts such as loss of property and landscape values (Carles, Barrio, & de Lucio, 1999; Jim & Chen, 2006; Luttik, 2000; Navrud, 2002; Wardman & Bristow, 2004; Wilhelmsson, 2000).

In urban residential areas, road traffic noise is a main source affecting sleep disturbance and annoyance. Therefore, courtyards have been widely used to prevent direct exposure of building façades to road traffic noise (Ettouney & Fricke, 1973; Öhrström, Skånberg, Svensson, & Gidlöf-Gunnarsson, 2006; Oldham & Mohsen, 1979). On the other hand, when background noise from road traffic is reduced, sounds from within a courtyard such as from social activities and conversation could become more important as sources of noise annoyance. For example, Kotani, Narasaki, Sato, and Yamanaka (2003) showed that "Children's voice" is ranked as the top noise source from a courtyard. Therefore, it is useful

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Fig. 1. Site conditions before (left) and after (right) the refurbishment using vegetation, wood decking and street furniture.

to study methods employing landscape designs to reduce sound energy propagation within a courtyard.

The sound field in a courtyard is influenced by many factors such as the shape and volume of the space, building layout surrounding a courtyard and the materials forming the building façade. These affect the characteristics of sound fields described by acoustic parameters such as reverberation time (RT) and sound pressure level (SPL) distribution. However, most courtyards have been designed without any acoustic consideration, which often leads to acoustic defects such as strong flutter echoes, long RT and increased sound levels due to geometrically reflecting façades with acoustically hard surfaces (Kang, 2000, 2002). These acoustic defects result in increased noise annoyance for occupants, especially in summer when the courtyard is used more, and windows are open for natural ventilation. Therefore, it is important to absorb and diffuse sound energy propagating in a courtyard. It is also important in the design of a suitable sound field for a comfortable courtyard soundscape to consider pleasant sounds such as fountains and bird song (Kang, 2007).

The typical method to control sound fields is to use acoustic absorbers and diffusers on the wall, ground and ceiling of a space. In enclosed spaces such as concert halls, absorbers and diffusers can be installed relatively easily since they are not contaminated by rain and dust, a reason why it is more difficult to mount commercial devices in open courtyards. Therefore, it is useful to identify outdoor acoustic materials for controlling the sound field by landscape designs.

Currently, vegetation grown on green roofs and walls has become popular in urban spaces due to numerous environmental benefits (Getter & Rowe, 2006; Ksiazek, Fant, & Skogen, 2012; Mentens, Raes, & Hermy, 2006; Veisten et al., 2012). Previous studies have also reported that vegetation can contribute to the mitigation of noise pollution, which suggests its potential use in controlling the sound fields of courtyards by landscape designs (Oldham, Egan, & Cookson, 2011; Van Renterghem & Botteldooren, 2008, 2009, 2011; Renterghem, Hornikx, Forssen, & Botteldooren, 2013; Wong, Kwang Tan, Tan, Chiang, & Wong, 2010; Yang, Kang, & Choi, 2012). With regard to soundscape concepts, greening inner courtyards with vegetation can also moderate noise annoyance by improving the aesthetic/natural appearance (Gidlöf-Gunnarsson & Öhrström, 2007, 2010; Langdon, 1976).

In general, vegetation consists of two main components: plant structures (leaf, stem and root) and the growing media (soil or substrate). Previous studies have shown that the plant structures can absorb and diffuse sound energy, especially at high frequencies (Martens & Michelsen, 1981; Watanabe & Yamada, 1996; Yang, Kang, & Cheal, 2013a; Yang, Kang, Cheal, Renterghem, & Botteldooren, 2013b). It has also been found that soil has similar properties to those of a porous material for absorbing sound energy (Kaye & Evans, 1940; Yang et al., 2013a).

The aim of this paper is therefore to investigate the acoustic effect of applicable landscape designs in courtyards, with particular attention to the acoustic effects of vegetation. This is done through a case study in a courtyard located in an accommodation building of the University of Seoul, where a quiet sound environment is required. The acoustic effect of landscape designs using vegetation has been examined using two methods: (1) in situ measurements before and after applying a practical landscape design; and (2) computer simulation for applicable landscape designs using vegetation in the courtyard. The acoustic parameters considered here are the extra SPL attenuation and RT. Based on the extra SPL attenuation in octave bands, a difference in speech levels before and after applying landscape designs are also calculated.

2. Methodology

2.1. Description of the studied site

The courtyard investigated in this study is located at the accommodation building in the University of Seoul, Seoul, South Korea. The courtyard has a rectangular shape with dimensions of 32.4 m (L) × 8.2 m (W). The site is surrounded by building façades with different heights, 7.1 m (3 façades) and 24.4 m (1 façade), as shown in Fig. 1. Fig. 2 illustrates the cross section and ground plan for the accommodation building.

As Fig. 1 shows, there was a refurbishment of the inner courtyard using vegetation, wood decking and garden furniture in January 2011. Before the refurbishment, the building façade and ground of the courtyard had geometrically reflecting surfaces with acoustically hard materials such as marble and glass. Therefore, it was expected that there would be acoustic defects such as strong flutter echoes, long RT and increased sound level due to multiple reflections, which can cause increased noise annoyance for occupants in the courtyard. Sound levels in front of the windows at different floor levels play an important role in determining the life quality of the occupants. In particular, students in bedrooms from the 1st to 7th floor facing towards the courtyard have expressed strong complaints about noise for from the courtyard. Noise annoyance is mainly due to excessive sound levels for conversation, the sound energy of which is increased by multiple reflections between geometrically reflecting facades. Therefore, architectural treatments using appropriate acoustic materials to reduce sound levels in front of the accommodation building are also required.

To improve the students' living environment, the university office has decided to refurbish the whole ground and a part of the building façades using low-growing vegetation, small trees, wood decking and garden furniture, as shown in Fig. 1. The wood decking