Application of University Campus Noise Map Based on Noise Propagation Model: A Case in Guangxi University

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Abstract: Considering the characteristics of a campus environment and the rules that govern outdoor sound propagation, this paper identifies traffic noise as the dominant noise source of the campus environment based on the measurement of the noise environment. A noise propagation model that is suitable for university campuses was developed and used to create a noise map of the ambient area of the teaching building on the campus of Guangxi University. This noise map was then utilized to analyze the noise environment. The results revealed that for a given teaching building, the noise disturbance on high-rise classrooms is more significant compared to the impact on low-rise classrooms. Attention should then be paid to noise control in the high-rise classroom of the building. By appropriately increasing the distance between the building and the main traffic road or by adopting a judicious soundscape design that considers the shape of the building, it is possible to effectively reduce the interference of noise during teaching activities in a building and improve the sound quality of the campus environment. The results of this study provide a theoretical framework for the governance of the campus acoustic environment.

Keywords: noise propagation model; noise map; soundscape; optimization

1. Introduction

Noise pollution is a major environmental hazard that not only affects our daily work and life, but also poses a danger to our health [1]. Numerous studies [2–4] have shown that noise not only directly causes hearing loss, but also increases annoyance and insomnia [5,6], increases the risk of arteriosclerosis and coronary heart disease [7–9], and negatively impacts mental health [10]. Noisy conditions on university campuses have direct negative effects on students’ learning and also on the teaching environment of many teachers [11,12]. Whereas sounds from waterscape, green belt, and birdsongs on campus are perceived as being very pleasant and could be the desired soundscapes to mitigate noise impact [13,14]. In recent years, the noise sources on university campuses have become complex and diverse, and the resulting noise pollution has become increasingly problematic [15]. This has the potential to adversely affect a student’s attention span, memory, and understanding, and negatively impact teaching activities [16–19]. Since classroom teaching is a gradual and continuous thinking process, noise on campus will seriously affect classroom teaching and interrupt students’ thinking, make teachers raise their voices, increasing their tiredness, distract students from their attention, and finally, worsen the teaching effect. For the purpose of raising awareness of noise problems in schools, Ascari et al. [11] carried out the Gioconda project of monitoring noise exposure in eight schools in Italy and found that the external noise level in each case exceeds the law limits.

Given that teaching activities are performed on university campuses, an appropriate acoustic environment can help to improve teaching and the routine life quality of teachers and students [20,21]. Therefore, it is necessary to accurately evaluate the environmental noise on campus and to implement timely measures to control noise. In this regard, a
A noise map is an effective technique to meet the requirements of planners and designers investigating the impacts of anthropogenic noise, mitigating the noise impacts on the environment, and solving novel issues in soundscape ecology [29]. It can be used to predict and evaluate the acoustic environment of a built area and propose improvement measures. Moreover, noise maps are critical in helping planners understand the noise distribution of an area of interest and addressing noise issues in a targeted manner. The study of urban noise maps was first reported in Europe [22,30]. A noise map of Birmingham in the United Kingdom was created in 2000 [31]. Subsequently, cities such as Madrid, Spain and Lisbon, Portugal also plotted their noise maps [32,33]. Given that a traditional static noise map only shows the mean noise level in a certain area and does not show temporal and spatial variations in noise level, the development of a noise map that can dynamically reflect the real-time change of noise has attracted researchers’ interest. Considering the urban area of Samara, Russia as an object, Vasilyev [34] proposed a noise mapping method that reflected the dynamic change of noise and drew a dynamic noise map. Mishra et al. [35] used ArcGIS 10.4 software to create a dynamic noise map of road traffic noise in Delhi, India. Lesieur et al. [36] proposed a novel model to increase the speed and accuracy of generating dynamic noise maps. Licitra et al. [29] reviewed the EU’s 20-year development in noise maps and introduced the effective experience and methods for applying noise maps. They narrated the development of EU policy on noise by implementing the Environmental Noise Directive (END), which applies to people who are exposed to built-up areas, such as near
schools, hospitals, and other noise-sensitive buildings and areas. It requires member states to issue noise maps and noise management action plans for agglomerations, main traffic routes, and major airports every five years.

In 2008, the first urban noise map was created for the southern area of Futian, Shenzhen in China [37]. In 2012, Cai et al. [38] used the “Urban Environmental Noise Simulation and Evaluation System” to create a traffic noise map of Guangzhou. In recent years, three-dimensional (3D) dynamic noise maps have become a research topic for scholars. Cai et al. [39] proposed a method for creating urban traffic noise maps using supercomputers, which solved the problem with the creation of 3D dynamic noise maps consuming too much time in complex building environments. In order to attenuate highway traffic noise, Fu et al. [40] drew a 3D dynamic noise map based on a specific area, time period, and previous GPS traffic trajectory data, and proposed a computational model for predicting traffic noise.

In contemporary university campus environments, noise pollution is a serious problem that cannot be ignored. However, it is difficult to predict and control. In order to predict terrestrial outdoor noise propagation, Alexander et al. [41] developed open-source Sound Mapping Tools (SMT) which includes three sound propagation models. Noise maps, therefore, can provide a basis for acoustic environmental planning of campuses and the design of sound insulation of teaching buildings. Using in situ measurements, we determined the sound power level of sources, established a dominant noise propagation model that accounted for the characteristics of a university campus environment, and generated a noise map of the surrounding area of teaching buildings. Aiming at the plane and spatial distribution of noise pressure levels, this study proposes a regulation approach for noise control and provides an optimization strategy for the acoustic environment on university campuses.

2. Measurement of Campus Acoustic Environment

Tong et al. [42] explored the relationship between noise complaints and urban density in cities of different levels of density and indicated that noise complaints increased with increasing urban density. University campuses which are also crowded and high traffic flow environments are characterized by their acoustic environments. Guangxi University was used as a case study to describe the process of establishing a campus noise propagation model. This institution is located in Nanning, a city in southern China. Its location is shown in Figure 2. Based on the analysis of the campus morphology, such as distribution of campus buildings, road layout, greening, terrain, etc., and an extensive investigation of the campus acoustic environment; considering the classrooms near the main roads are the most noise-polluted [11], we selected three main roads with a significant impact on the teaching area in terms of noise and the highest traffic flow, namely Junwu Road, Tonghe Road, and Shatang Road, corresponding to the blue, pink, and black lines in Figure 2b, respectively. Based on factors such as campus layout, planning characteristics, traffic flow, and daily routines, we set up the measuring points and measured the noise conditions of the three roads. The distribution of the measuring points is shown in Figure 3.

According to the requirements outlined in the “Environmental quality standards for noise” (GB 3096-2008) [43], the in situ measurements were conducted during teaching hours. The measurement periods were 8:00 to 12:00 a.m. and 14:30 to 17:30 p.m. Measurements were performed using a BSWA801 sound and vibration analyzer. The analyzer utilized a DSP (Digital Signal Processing) signal processing chip and can perform real-time 1/1 and 1/3 octave spectrum analysis, real-time FFT spectrum analysis, and reverberation time testing [44]. The measurement result was expressed in equivalent SPL (sound pressure level) $L_{eq}$. Figure 4 shows that the noise SPL of the three main roads on campus increase as the frequency increases. Their varied SPL range was between 45 dBA and 55 dBA, and its fluctuation was small. Figure 5 shows the traffic flow for each period during the monitoring time. Based on the traffic flow data, it was determined that the high-frequency noise on the
main road is more prominent because there were many pedestrians on the campus road, and the drivers in passing vehicles often honked their horns to alert pedestrians.

Figure 2. Geographical location: (a) The location of Guangxi Prov. in China; (b) the location of Guangxi University in Nanning.

Figure 3. Distribution of measuring points: (a) Junwu Road; (b) Tonghe Road and Shatang Road.

Figure 4. The measured value of the equivalent noise level of the road $L_{eq}$ (dBA): (a) Junwu Road; (b) Tonghe Road; (c) Shatang Road.
3. Noise Propagation Model on Campus

By starting with the sound power level of the noise source, a noise propagation model generates spatial noise maps of predicted sound pressure level (SPL) and then calculates a series of SPL attenuations [41]. Based on the principle of outdoor sound propagation, when the vertical distance from the receiving point to the noise source is much greater than the length of the source, this noise source can be simplified as a point source. The relationship between the directivity factor of the noise source and the sound intensity, sound pressure, and sound power radiated by the noise source at the receiving point is given by:

\[
I = \frac{p^2}{\rho_0 c_0} = \frac{WQ}{4\pi r^2},
\]

(1)

where \(I\) is the sound intensity at the receiving point, measured in W/m², \(W\) is the radiated sound power of the noise source, measured in W, \(r\) is the distance from the noise source to the receiving point, measured in m, \(Q\) is the directivity factor of the noise source, \(P\) is the sound pressure at the receiving point, measured in N/m², and \(\rho_0 c_0\) is the product of the air density \(\rho_0\) and the speed of the sound wave in the air \(c_0\). Generally, \(\rho_0 c_0 = 420.2\ kg/(m²\cdot s)\).

When the vertical distance between the receiving point and the sound source is less than one-third of the length of the sound efficient linear source (such as road traffic noise as vehicles along the road), it can be considered to be an infinite linear noise source. We assume that the sound power of an infinitely long linear source is uniform along the length of the source. Then, we divide the infinitely long linear noise source into infinitesimal elements \(dx\) and consider each infinitesimal as a point source (as shown in Figure 6). The relationship between the sound pressure at the receiving point of the infinitely long linear noise source and the sound power of the noise source is given by:

\[
p^2 = \rho_0 c_0 \int \frac{WQ}{4\pi r^2} dr = \frac{\rho_0 c_0 WQ}{4\pi} \int \frac{1}{r^2} dr,
\]

(2)

where \(dx = rd\theta\). The lower and upper limits of the integral of an infinitely long linear noise source are \(\pi/2\) and \(-\pi/2\), respectively. Then, Equation (2) can be expressed as:

\[
p^2 = \frac{\rho_0 c_0 WQ}{4\pi} \int_{-\pi/2}^{\pi/2} \frac{\cos \theta}{r_0} d\theta = \frac{\rho_0 c_0 WQ}{2\pi r_0}.
\]

(3)
The sound pressure level at the receiving point is then given by:

\[
L_P = 10 \log \frac{P^2}{P_0^2} = 10 \log \frac{\rho_0 c_0 W Q}{2 \times 4 \times 10^{-10} \pi r_0},
\]

where \( L_P \) is the sound pressure level at the receiving point, measured in dB, \( P_0 \) is the reference sound pressure with a value of \( 2 \times 10^{-5} \) N/m\(^2\), \( r_0 \) is the vertical distance from the receiving point to the linear noise source (i.e., the equivalent lane centerline), which can be calculated as \( r_0 = \sqrt{r_1 r_2} \), where \( r_1 \) is the distance from the receiving point to the centerline of the nearest lane, measured in m, and \( r_2 \) is the distance from the receiving point to the centerline of the farthest lane, measured in m.

![Figure 6. Calculation diagram for linear noise source.](image)

The campus area was flat and considered as a semi-free sound field and \( Q = 2 \). The sound pressure level at the receiving point can be written as:

\[
L_P = L_W - 10 \log r_0 - 5,
\]

where \( L_W \) is the sound power level of the linear noise source, measured in dB. According to the description of the attenuation of outdoor sound propagation in the Technical Guidelines for Noise Impact Assessment [45], when we consider the attenuation of sound pressure level with distance in the process of sound propagation, we should also consider the attenuation caused by atmospheric absorption, ground effect, and barrier shielding, and provide a correction for these attenuations. Considering the environmental correction, the sound pressure level at the receiving point can be expressed as:

\[
L_P = L_W - 10 \log r_0 - 5 - \Delta L,
\]

where \( \Delta L \) is the correction considering the aforementioned attenuations, and is expressed as follows [45]:

\[
\Delta L = A_{atm} + A_{gr} + A_{bar} + A_{misc},
\]

where \( A_{atm}, A_{gr}, \) and \( A_{bar} \) are the attenuations caused by atmospheric absorption, ground effect, and barrier shielding, respectively. \( A_{misc} \) is the attenuation associated with miscellaneous factors including the attenuation owing to industrial areas, building groups, etc.

Figure 7 shows the sound power level of the noise source calculated using (6). In the figure, the sound power levels at low frequencies (63 Hz–500 Hz) are relatively low and uniformly distributed. The sound power level increases with frequency, reflecting the frequency characteristic of the anthropogenic noise propagation resulting from mixed traffic of people and vehicles in the campus environment.
whereas those located away from the main road are gradually less affected by noise. The expression as:

\[ PWL_{r \text{ L}} = -10 \log_{10}(\frac{L}{1}) - L_{\text{atm}} - L_{\text{gr}} - L_{\text{bar}} - L_{\text{misc}} \], (7)

where \( L_{\text{atm}}, L_{\text{gr}}, \text{ and } L_{\text{bar}} \) are the attenuations caused by atmospheric absorption, ground effect, and barrier shielding, respectively.

Figure 7 shows the sound power level of the noise source calculated using (6). In the frequency characteristic of the anthropogenic noise propagation resulting from mixed uniformly distributed. The sound power level increases with frequency, reflecting the figure, the sound power levels at low frequencies (63 Hz~500 Hz) are relatively low and increased to below 45 dB. The rooms close to the road are significantly impacted by noise, whereas those located away from the main road are gradually less affected by noise. By comparing the noise levels of the same measuring point at different heights, the noise level increases gradually as the height of the measuring point increases. Therefore, for the same position of the building plane, the high-rise classrooms are more seriously affected by road traffic noise than the low-rise classrooms. In summary, the adverse impact of traffic noise on the campus acoustic environment is significant and keeping the classroom away from the main road can reduce the noise disturbance evidently.

4. Layout Analysis Based on Noise Maps

We imported the acquired parameters of the noise propagation model into Predictor 7810 software to create a noise map of the surrounding area of the teaching building on the campus of Guangxi University. Predictor 7810 software is a professional environmental noise prediction software developed by Denmark B&K Company. The noise maps can be drawn, and they are used to evaluate, analyze, and predict the distribution of campus noise and its adverse impact on the teaching environment, and explore the optimization strategy for noise control on campus [46].

Figure 8 is the floor plan of the surrounding area of a teaching building. The shaded area in this figure is the teaching building. The east side of the building faces the main road of the campus with a high-traffic flow. The north and south sides face the secondary roads with lower traffic flows. Therefore, the noise is mainly attributable to the traffic noise from the main road on the east side. Figure 9 is the noise map of the surrounding area of the teaching building generated by the Predictor 7810 software. According to this noise map, the rooms that are located less than 10 m from the east exterior wall of the teaching building (the rooms between measuring points A and B) are most seriously affected by noise. The noise level exceeded 60 dB, which can cause serious interference to the daily teaching process. For the rooms located at a distance between 10 m and 20 m from the east exterior wall (the rooms between measuring points B and C), the interference noise is attenuated in the range of 55 dB~60 dB. For the classrooms located at a distance above 20 m from the east exterior wall (the room near measuring point C), the interference noise is decreased to below 55 dB, and the noise level of the west side of the teaching building is attenuated to below 45 dB. The rooms close to the road are significantly impacted by noise, whereas those located away from the main road are gradually less affected by noise. The other buildings in the figure have the same characteristics.

The specific noise level of each measuring point around the teaching building is shown in Table 1. By comparing the noise levels of different measuring points at the same height, the noise level from measuring point A to measuring point C gradually decreases. This indicates that as a building shifts farther away from the main road, the measuring point is less affected by noise. By comparing the noise levels of the same measuring point at different heights, the noise level increases gradually as the height of the measuring point increases. Therefore, for the same position of the building plane, the high-rise classrooms are more seriously affected by road traffic noise than the low-rise classrooms. In summary, the adverse impact of traffic noise on the campus acoustic environment is significant and keeping the classroom away from the main road can reduce the noise disturbance evidently.
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By analyzing the noise level distribution of the ambient environment of the teaching building and comparing the two design schemes (Schemes 1 and 2), the optimized measures of the campus acoustic environment were further developed.
Scheme 1: From the aforementioned results, when the teaching building is withdrawn from an appropriate distance, making the classroom far away from the campus main road can mitigate the impact of traffic noise. So, a noise map was created, as shown in Figure 10, as the teaching building was set back at a specific distance. The noise level of each measuring point near the teaching building is listed in Table 1. Compared with Figure 9, Figure 10 indicates that setting the teaching building back a set distance and increasing the distance from the main road can reduce noise disturbance. The noise level of the classrooms near the main road was reduced to below 60 dB. The noise level of the classrooms near measuring point C decreased below 55 dB. It can be observed that the noise level around the teaching building is significantly reduced after setting the teaching back. As a consequence, the interference with teaching activities is also likely to be weakened. Simultaneously, the noise level of the classrooms on the west side of the teaching building was attenuated to below 40 dB, so the interference to teaching activities is negligible and the acoustic environment is acceptable. Therefore, if there are sufficient spaces, positioning the teaching building as far away from the main road as possible can significantly enhance the external acoustic quality around the building.

Scheme 2: Given that the distance that the building can be set back is limited by the site area when the noise reduction effect of Scheme 1 is not significant, the sound barriers, sound masking between the receiver (teaching building) and sound source (the main road), and even soundscape can be introduced. Some studies [42,43] have shown that compared with the urban environment, the soundscape elements from the natural environment, such as birdsong, wind blowing trees, the sound of running water, etc., are more pleasant, enjoyable, friendly, and enchanted, which can alleviate the person’s stress caused by noise disturbance. For example, in Figure 11, the design scheme with the waterfall wall and fountain hinders noise propagation through the wall and utilizes the soothing sound of the waterfall and fountain to mask the traffic noise. In addition to attenuating the noise level, this scheme can also weaken the annoyance induced by noise and promote a positive experience. Figure 12 shows the noise map after the teaching building is set back and the soundscape (a waterscape involving waterfalls, fountains, and green potted plants) is adopted. The specific noise levels of the nearby measuring points are displayed in Table 1.
Figure 10. Noise map of the teaching building (Scheme 1).

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points are displayed in Table 1.

Figure 11. Schematic view of soundscape: (a) Perspective view; (b) elevation view.

Figure 12. Noise map of the teaching building (Scheme 2: with soundscape).

5. Optimization and Discussion

Comparing Figure 12 with Figure 10, we find that the waterscape with waterfalls 
and fountains has a significant effect in terms of adding to the acoustic quality of the 
environment. After the building is set back and the waterscape (soundscape) design is 
adopted, the noise level of most classrooms near the roadside of the teaching building is 
reduced to below 55 dB. This indicates that this scheme has an evident noise reduction 
effect on the teaching building. By comparing the noise maps on the building façade shown 
in Figure 13a (without soundscape) with that shown in Figure 13b (with soundscape), 
it can be seen that the noise levels of the low-rise classrooms in the teaching building 
are significantly reduced. However, the noise levels of the high-rise classrooms are still 
above 60 dB, with almost no attenuation. Therefore, for relatively tall buildings, the noise 
reduction effect of waterscape design on high-rise rooms is not significant. We can consider 
designing a step-like building, wherein the high-rise rooms are set back layer by layer. 
Figure 14 shows the noise map after the high-rise classrooms of the teaching building 
are set back layer by layer. It is observed that in this case, the noise level of the high-rise 
classrooms is reduced below 60 dB, and the noise reduction effect is acceptable.
which represents a reduction of 4.5 dB. However, the noise levels of measuring point from the ground is 1.5 m, comparing Schemes 1 and 2, it is found that the noise level of measuring point A is decreased from 56.5 dB (Scheme 1) to 52.0 dB (Scheme 2), which represents a reduction of 4.5 dB. However, the noise levels of measuring point B and measuring point C are only reduced by 0.1 dB, with little noise mitigation. By analyzing each measuring point with a height of 5.1 m or 8.7 m from the ground using the same method, the same phenomenon of noise mitigation was observed. When Scheme 2 was adopted, the soundscape design, the noise level at measuring point A decreased significantly, and the noise levels reduction at measuring points B and C were not obvious. Therefore, the soundscape design (Scheme 2) only has a significant noise reduction effect on the east side of the building (the side close to the soundscape). However, there is almost no noise reduction effect on the west side of the building (the side farther from the noise source).

6. Conclusions

Given that road traffic noise is the dominant noise source of the investigated campus and existing traffic noise propagation models are designed for urban environments, it was necessary to establish a noise propagation model for a campus acoustic environment. In this study, the road traffic noise on a university campus was measured, and analyzed the relationship between the measured noise level at the receiving point and the sound power level of the noise source to establish a noise propagation model. The model fully characterized the campus anthropogenic noise propagation. The proposed noise propagation model is applied to create a noise map around the teaching building and determined that road traffic noise had a significant adverse impact on the campus acoustic environment. The

Figure 13. Noise map of the teaching building elevation (a) without waterscape and (b) with waterscape.

Figure 14. Noise map of the receding teaching building (step-like).
noise level around the teaching building was relatively high, especially in the classrooms close to the main road, for which the noise level was above 60 dB, which has the potential to cause interference with teaching activities. In addition, it is found that the farther the teaching building is from the main road, the less the effect owing to noise. At the same position on the building plane, the high-rise classrooms are more adversely affected by noise than the low-rise classrooms. Thus, more attention should be directed to noise control in high-rise classrooms.

Accordingly, two optimized schemes were proposed to reduce the impact of noise during teaching activities and enhance the acoustic environment quality. Research indicates:

1. “Setting back the building” can improve the acoustic environment of all classrooms in the teaching building. In the case of what the site allows, setting back the building as far as possible from the main road of the campus can significantly improve the acoustic environment around the building and effectively reduce the adverse impact of campus noise.

2. Since the noise reduction effect for the high-rise classrooms and the west side of the building (the side away from the noise source) is marginal, the measures for noise reduction can cooperate with the building shape design, making the teaching building upper part receding, and can attenuate noise level in the high-rise classrooms and the west side of the teaching building.

3. The soundscape design has a certain noise reduction and sound masking effect on the low-rise rooms of the east side of the building (the side close to the soundscape). However, it can only improve the acoustic environment of the low-rise classrooms on the east side of the teaching building (the side close to the soundscape). Due to construction land restrictions, the landscape area should not be too large. Therefore, when attempting to regulate anthropogenic noise on the campus, we should focus on “setting back the building”, supplemented by “soundscape design”.

4. It is necessary to implement measures to reduce the flow of vehicular traffic that enters the teaching area and reduce the sound power level of the noise source to improve the quality of the campus acoustic environment.

The situation of the internal noise in the classrooms not investigated in this paper depends on external noise on the façade, the sound insulation of the building, the background noise (e.g., from heating and ventilation machinery), building acoustic characteristics, etc. Research on the internal noise environment can be carried out after mastering the sound insulation performance of the façade and wall, since most of the teaching buildings on campus were built in the 1990s, using lightweight structures with poor sound insulation.

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