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Virtual Reality for Case-based Learning of The Propagation of Urban Traffic Noise in Residential Areas

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Abstract. Noise pollution is a growing environmental concern worldwide and its impact assessment is an important content in engineering education and vocational training for environmental impact assessment. Traffic noise is one of the most common sources of urban noise pollution, thus its propagation in residential areas needs to be learned by practitioners. For this teaching content, the combination of case-based learning and virtual reality is desirable but challenging due to time-consuming production processes and less intuitive audio-visual experience. This paper proposes a virtual reality-based case generation system for the propagation of urban traffic noise in residential areas. Virtual scenes are parametrically constructed based on urban residential areas with surrounding traffic and noise reduction facilities. The computation of noise in the scene associates virtual scene with noise environment and synchronizes scene roaming with noise experience. Ultimately, a case study confirms the validity, reliability and vividness of the proposed case generation system.

Keywords: Virtual reality, Case-based learning, 3D modelling, Urban residential area, Traffic noise propagation
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1 INTRODUCTION

Environmental impact assessment was introduced in universities in the 1970s and nowadays it has been well established in higher education worldwide [1-3]. Legislation in more than 180 countries or regions stipulates that environmental impact assessment must be conducted before construction projects start and therefore there is a growing demand for certified experts such as registered environmental impact assessment engineers in China. In engineering education and vocational training for environmental impact assessment, noise propagation and attenuation are indispensable teaching contents. With the construction of urban traffic networks, noise pollution caused by road traffic and rail transit has been in focus for the last few years [4-6]. Consequently, practitioners need to learn the propagation of urban traffic noise in residential areas.

Case-based learning utilizes historical or hypothetical cases that involve solving problems and/or making decisions [7] and it has been successfully adopted in the teaching of law, business, medicine, science and engineering courses [8-10]. Well-designed teaching cases inspire trainees to do more thinking and aid them in understanding abstract theoretical knowledge, which is especially suitable for vocational training. In terms of engineering education and vocational training for the propagation of urban traffic noise in residential areas, case-based learning can reflect the characteristics and interactions of environmental elements such as terrain, traffic, buildings, residents and plants, assisting trainees to grasp the theoretical knowledge and professional skills of environmental impact assessment more systematically and to apply them to engineering projects more efficiently. Different from general teaching cases with descriptive texts and on-site photos as the description of case scenarios, teaching cases for the propagation of urban traffic noise in residential areas need to present noise intensity and noise distribution of case sites. Interactive audio-visual experience is more intuitive and thus preferable.

Virtual reality brings participants a sense of presence by deceiving people's senses and provides them with humanized man-machine operations and natural feedback in a virtual environment, which is helpful for higher education and vocational training [11-13]. The combination of case-based learning and virtual reality provides vivid audio-visual presentations and rich interactive content and significantly improves teaching quality [14-16]. With regard to case-based learning of the propagation of urban traffic noise in residential areas, virtual reality-based teaching cases can reflect the visual and auditory characteristics of environmental elements through 3D models and audio playback, restoring terrain, traffic, buildings, facilities, residents and plants in real environments with high fidelity. However, noise at different positions in the virtual environment of a teaching case should be different. Ignoring the propagation and attenuation of noise is acceptable for small-scale scenes, but not convincing for larger or more complex scenes such as urban residential areas. Consequently, it is time-consuming to establish teaching cases for the propagation of urban traffic noise in residential areas, and it is challenging to provide intuitive and interactive audio-visual experiences in the virtual environment of these teaching cases.

In this study, we present a virtual reality-based case generation system for the propagation of urban traffic noise in residential areas. Virtual scenes of urban residential areas with surrounding traffic and noise reduction facilities are parametrically built based on virtual reality. The noise in the scenes is computed using noise mapping and then fed back into the scenes to establish complete audio-visual teaching cases. The virtual environment of the teaching cases makes the association between the virtual scene and the noise environment and ensures the synchronization between scene roaming and noise experience. Additionally, a case study is conducted for an urban residential area in Beijing with its surrounding traffic to verify the effectiveness of the proposed case generation system.

2 METHODOLOGY

2.1 System Design

The proposed case generation system is based on Unity, a virtual reality development toolkit. It consists of three modules, namely scene modelling, noise prediction and system management, as shown in Figure 1. The scene modelling module constructs the 3D virtual scene of urban residential areas with surrounding road traffic, rail transit and noise reduction facilities. The noise prediction module performs the conversion of the virtual reality scene into a geographic information model, the calculation of the noise environment in the virtual scene and the generation of virtual reality-based teaching cases. The system management module configures the operation authority of project staff to protect key data hierarchically and records operation logs for problem tracing.

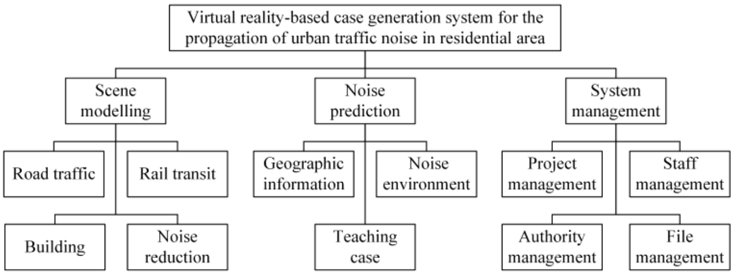

Figure 1: Functional decomposition of the case generation system.

2.2 Scene Modelling

Scene modelling underlies the forecast and evaluation of the noise environment in urban residential areas and thus it requires geometrically accuracy and perceptually fidelity. There are growing impressive works that designed and implemented virtual reality-based 3D environments in recent years [17-19]. Therefore, virtual reality is adopted for scene modelling of urban residential areas with surrounding traffic and noise reduction facilities. A graphical description of the scene modelling procedure is presented in Figure 2.

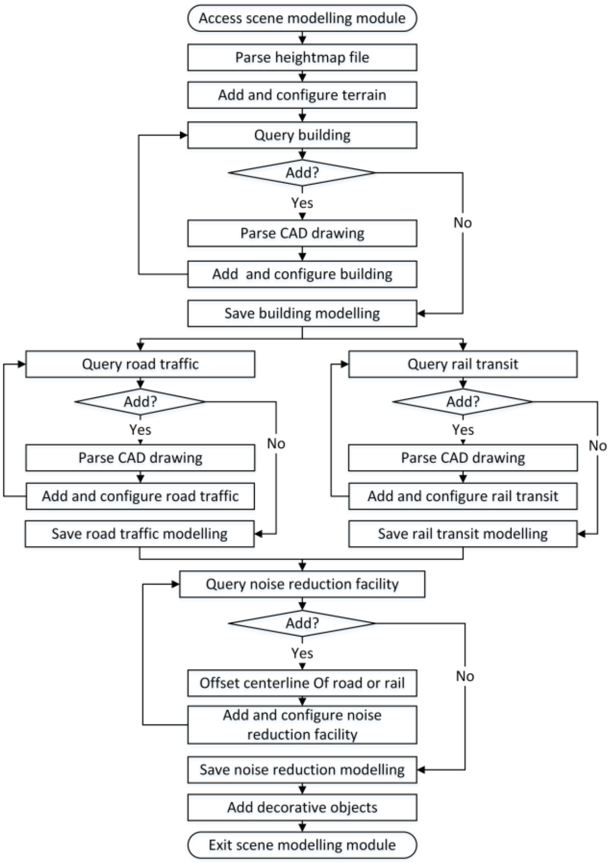

Figure 2: The workflow of scene modelling.

There are five main types of scene objects in the virtual scene. The terrain is the basis of a 3D scene and it enhances the realism of the scene. The terrain object in a scene is produced by reading a heightmap file, a grayscale image in which different grayscales represent different heights. Buildings are the main body of a 3D scene, reflecting the stereoscopy and uniqueness of the scene. Road traffic and rail transit are noise sources in the area and they increase the complexity of the virtual scene. The geometry and layout parameters of buildings, roads and rails are programmatically obtained from the corresponding layers of CAD drawings. Noise reduction facilities serve to reduce noise and display information or art and they are the embodiment of traffic noise control in the scene. They can be built parallel to roads or rails based on distance, height and type parameters. Texture files are configurable for road surfaces, building façades, building roofs and noise reduction facility surfaces. Besides, there are some decorative objects in the scene, such as people, plants and street lights. Based on a built-in 3D model library, they are generated randomly or uniformly by density or distance parameters in specific areas of the scene.

2.3 Noise Prediction

Level prediction and impact assessment of noise pollution are usually performed based on noise mapping [20-22]. For traffic noise, noise mapping computes the noise distribution in an area according to the noise source and propagation models such as FHWA [23], CNOSSOS-EU [24] and ASJ RTN [25]. In China, the noise prediction model in technical guidelines for noise impact assessment HJ 2.4-2009 plays a pivotal role in the forecast and evaluation of traffic noise pollution[26]. The proposed case generation system adopts the noise prediction model HJ 2.4-2009 to compute the noise in the virtual scene. Figure 3 outlines the conversion from virtual scenes to geographic information, noise environments and teaching cases.

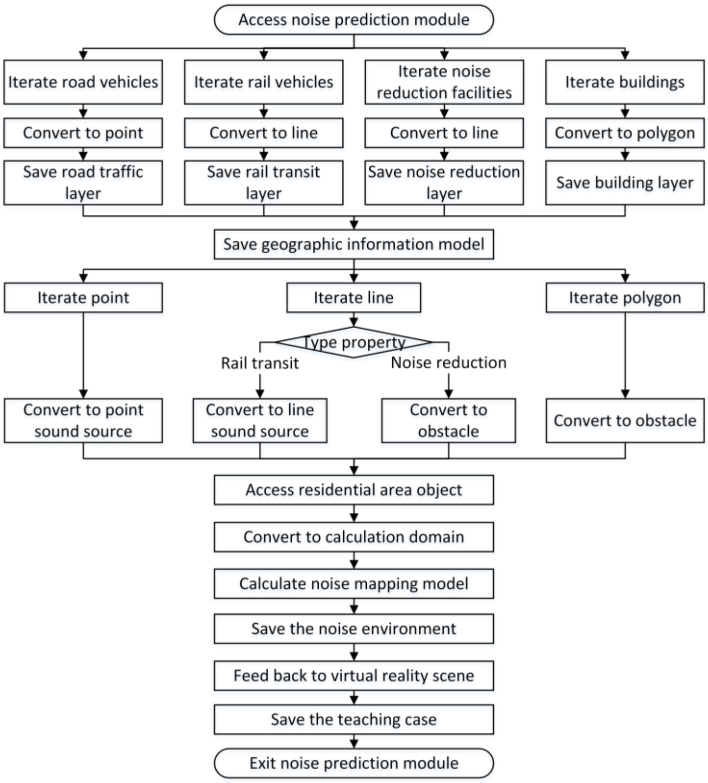

Figure 3: The workflow of noise prediction.

The type, speed and acceleration of each road vehicle are assigned to the noise emission model for the noise production computation. The position and noise emission of each road vehicle is allocated to the sound propagation model for the individual contribution calculation at a particular time. The calculated noise is then fed back to the virtual scene. The audio signal of an attenuated noise is attained by filtering that of the original noise with a graphic equalizer based on the octave frequency band A-weighted sound pressure level of the sound attenuation from the reference point to the prediction point. The audio signal of each attenuated vehicle noise is superposed to obtain the noise signal at a particular moment and a specific location in the scene. The virtual scene is consequently associated with the noise environment, which established a complete audio-visual teaching case based on the residential area. For recording the user's subjective experience during scene roaming in real-time, a pop-up list containing five levels is designed for users to select their noise annoyance levels. The subjective perception of noise is stored together with location information, which permits a comparison between objective calculation and subjective perception.

3 RESULTS AND DISCUSSION

3.1 A Residential Area as a Case

Take a residential area in Beijing as a case of the propagation of urban traffic noise in residential areas, as shown in Figure 4. There are 26 buildings in the residential area, most of which are for residential use and a few for commercial use. The buildings in the residential area are mainly arranged in four columns, the height of which gradually decreases from west to east. The buildings in the westernmost column have eight floors, with a gable roof on top. The buildings in the easternmost column have three floors, with a pyramid roof on top. The residential area has five entrances, one in the north, one in the east and three in the south. Cars can enter and leave the residential area through the north or south entrance. The southwest entrance of the residential area is connected to the entrance of an underground parking lot.

Figure 4: A residential area in Beijing as a case.

There are four roads around the urban residential area. The road on the west side of the residential area is an urban arterial road with heavy traffic. The other three roads are branch roads and the traffic flow on the north side of the residential area is significantly larger than that on the south and east side of the residential area. Figure 5 shows the octave frequency band A-weighted sound pressure level of road traffic around the residential area. No additional noise reduction facilities, such as sound barriers, are installed along these roads. Rail transit lines in this region are underground and far away from the residential area, which means that rail transit has little impact on the noise environment of the area. Therefore, the contribution of rail transit is ignored during the noise pollution assessment of the residential area.

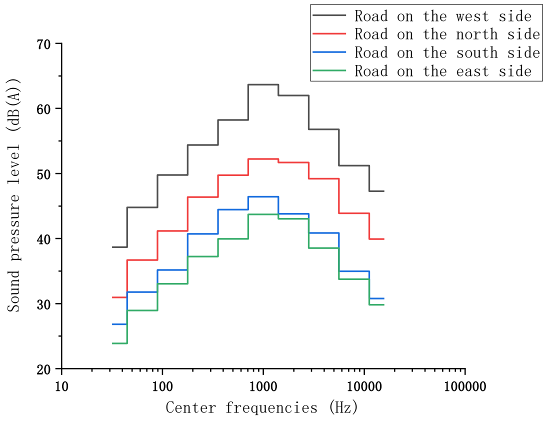

Figure 5: Octave frequency band A-weighted sound pressure level of road traffic near the residential area.

3.2 Validity

To confirm the validity of the proposed case generation system for the propagation of urban traffic noise in residential areas, a teaching case was established based on the above residential area. First of all, the system administrator created a project and assigned project staff and their authorities. Subsequently, project staff filled in the basic information of the teaching case corresponding to the project and then conducted scene modelling, noise prediction and case generation in the system. To represent the audio-visual environment of the residential area more realistically, test engineers provided noise audio files of road traffic near the residential area through on-site tests, and CAD engineers offered ground cover texture files, surface texture files of roads, facade and roof texture files of buildings. They imported these files into the case generation system through the file management submodule. Based on the project ID provided by the system administrator, trainers logged into the system and then filled in the basic case information. Next, the coordinate system, heightmap and ground cover texture of the residential area were configured in the scene modelling module. Afterwards, they selected the road CAD drawing and layers in the road traffic submodule and then configured surface texture and traffic noise for roads. Also, they chose the building CAD drawing and layers in the building submodule and set façade textures and roof textures for buildings. People, plants and other decorative objects were randomly produced around buildings and on both sides of roads based on a built-in 3D model library. After saving scene configurations, the system automatically formed a virtual reality scene. Scene modelling was followed by the noise prediction of the virtual scene. The geographic information was automatically extracted from the scene objects in the virtual scene and then integrated to form a geographic information model for the urban residential area. The acoustic features of roads and buildings were associated as attributes with the corresponding features of the geographic information model. Based on the obtained noise mapping model, the case generation system computed the noise in the calculation domain, namely the entire residential area. The results were fed back to the virtual scene, which associated the virtual scene with the noise environment and established an intuitive and interactive audio-visual teaching case based on the residential area, as shown in Figure 6.

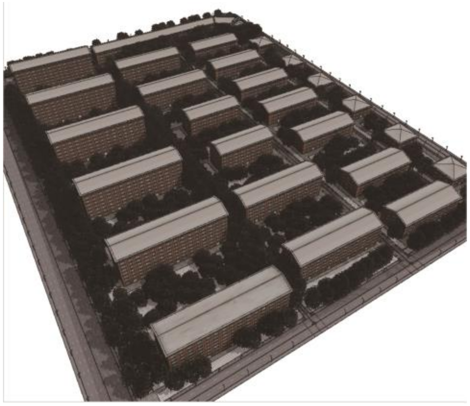

Figure 6: The virtual reality-based teaching case based on the residential area.

For evaluating the reliability of the proposed case generation system, the calculation results based on the above urban residential area are discussed. A visual representation of the noise distribution in the area can be seen in Figure 7, where different colours represent different equivalent sound pressure levels. In general, the western part of the residential area has the largest noise, followed by the north, and the southern and eastern parts have lower noise. The overall noise distribution in the residential area is consistent with the traffic intensity of roads around the residential area. The noise in the north and south of the residential area is larger than that in the middle. This is because the two northernmost buildings and the four southernmost buildings in the residential area are generally parallel to the roads on the north and south sides and these buildings prevent traffic noise from the north and south from directly propagating to the interior of the residential area. The attenuation of traffic noise in the western part of the residential area is slower than that in the north and south parts, which is attributed to the fact that the six westernmost buildings in the residential area are perpendicular to the roads on the west side rather than parallel. This arrangement avoids the residents of the westernmost buildings from suffering severe traffic noise pollution of the road on the west side but slows down the attenuation of traffic noise to a certain extent. Consequently, the noise distribution computed by the proposed case generation system is reasonably credible.

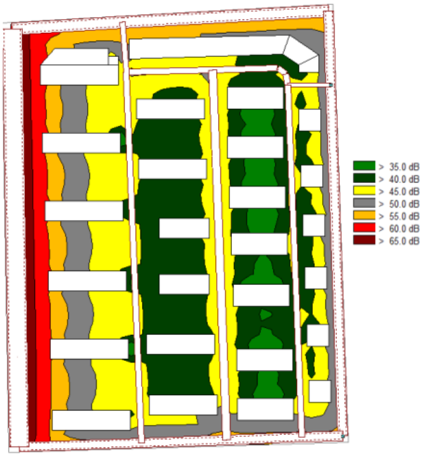

Figure 7: Noise distribution at a height of 1.5 meters in the residential area.

3.3 Effectiveness

Conventional teaching cases for environmental impact assessment of traffic noise describe case sites by descriptive texts and on-site photos and present a noise environment through the mapping of noise level indicator contours such as in Figure 7. Noise level indicators are abstract and do not, by themselves, provide a complete picture of traffic noise impacts on the affected communities. For example, Is the 3 dB difference in equivalent continuous A-weighted sound pressure level significant? what does 65 dB noise sound like? Different from traditional teaching cases, virtual reality-based teaching cases produced by the proposed case generation system provide trainees with interactive case scenarios and allow them to intuitively hear the noise in real-time while roaming in 3D virtual scenes. Besides, trainees can record their noise annoyance level in the virtual environment whenever they like, at which time the virtual reality-based teaching case will automatically store their subjective judgments with their locations. When roaming to predetermined evaluation locations, trainees are reminded to determine their feeling about the environmental noise here. The case generation system, therefore, underlies a comparison between objective calculation and subjective perception of a noise environment.

The proposed case generation system can be beneficial to case-based learning of the technical methods for noise impact assessment. To teach the attenuation of sound during propagation outdoors, a trainer may recommend the roaming route in Figure 8 to trainees. At the northern entrance of the residential area, trainees can clearly hear the sound of nearby road vehicles. At the first turn of the route. noise is slightly reduced. When they walk east to the second turn of the route, the traffic noise heard will become significantly smaller and duller. Then while they walk west to the west part of the residential area, the traffic noise heard will gradually increase. From this virtual reality-based teaching case, trainees may study a lot. Firstly, the volume of environmental noise at locations near roads is generally higher than that far from roads, which manifests that the traffic-induced environmental noise attenuates as the distance from road sound sources increases. Secondly, the environmental noise at locations far from roads is typically duller than that close to roads, which means that low-frequency noise attenuates faster than high-frequency noise. Thirdly, the environmental noise at a location without a building between it and roads is louder than that with a building between it and roads, which reflects the blocking of direct sound by buildings and the attenuation of diffraction sound due to the increase in distance. The proposed case generation system provides an interactive audio-visual teaching tool for the impact of road location and building layout on the attenuation of traffic noise during propagation outdoors, vividly complementing formula interpretation of noise propagation and data analysis based on noise distribution contour maps.

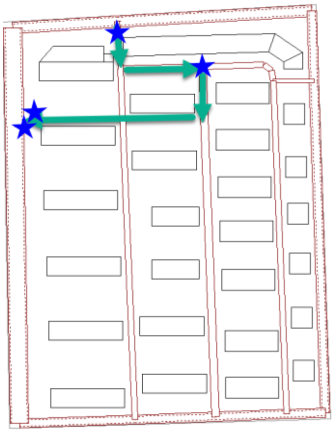

Figure 8: A roaming route and predetermined evaluation locations in the teaching case.

Additionally, the proposed case generation system may be helpful to case-based learning of the technical guidelines and standards for noise impact assessment. To explain noise limits of different environmental noise functional zones specified in the Chinese Environmental Quality Standard for Noise GB 3096-2008, a trainer may add predetermined evaluation locations along a roaming route in the virtual reality-based teaching case, as shown in Figure 8. At each predetermined evaluation location, trainees can learn something. The first predetermined evaluation location is at the north entrance of the residential area, as shown in Figure 9. The environmental noise here is about 60 dB, the day-time noise limit in urban zones with business and finance as the main function. The second predetermined evaluation location, as seen in Figure 10, is at the second turn of the route, where the noise environment experience is comfortable. The environmental noise here is slightly less than 55 dB and areas with lower environmental noise are suitable for housing, education, health care, scientific research and administrative offices. Figure 11 illustrates the virtual scene near the third predetermined evaluation location which is on the west side of the buildings in the west of the residential area. The environmental noise here is about 65 dB which is the day-time noise limit in urban zones for industry, warehousing and logistics. Figure 12 provides a scene representation of the fourth predetermined evaluation location which is near the urban arterial road on the west side of the residential area. The environmental noise here is approximately 70 dB which is the day-time noise limit for urban zones adjacent to traffic arteries. Trainees here will be severely disturbed by traffic noise. The proposed case generation system enables trainees to intuitively experience noises of different intensities as well as the influence of these noises on annoyance level and attention shift, urging trainees to do more thinking by substituting abstract noise level indicators with the intuitive audio-visual perception.

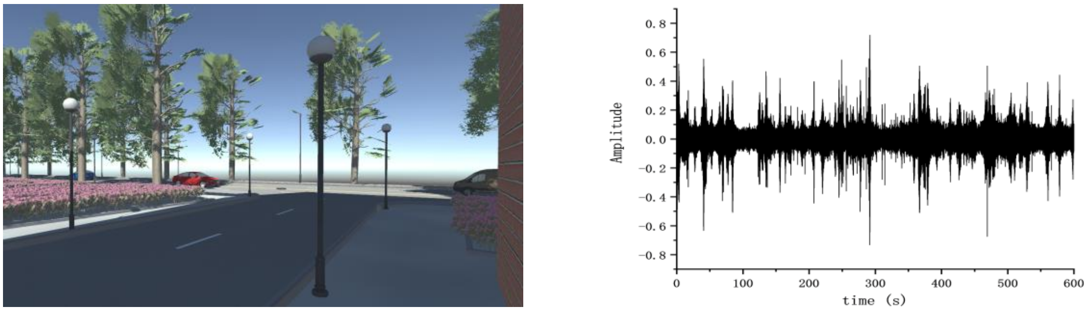

Figure 9: The first predetermined evaluation location: (a) Virtual scene, (b) Noise signal.

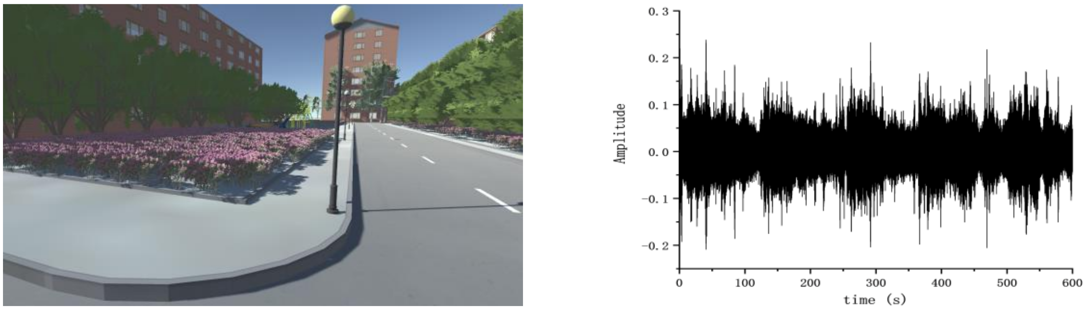

Figure 10: The second predetermined evaluation location: (a) Virtual scene, (b) Noise signal.

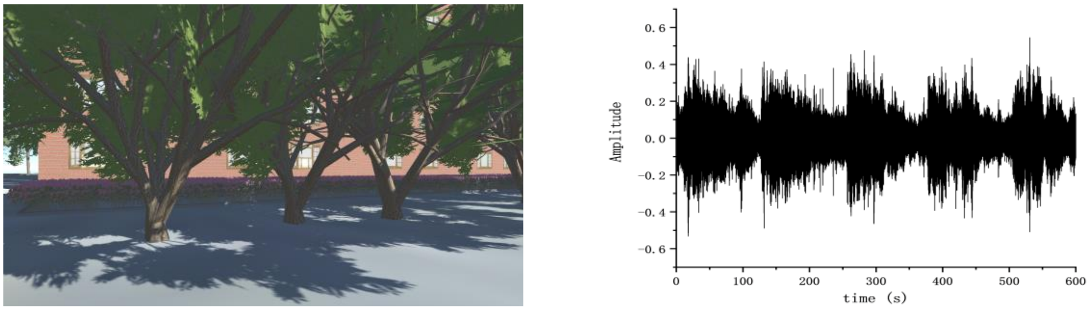

Figure 11: The third predetermined evaluation location: (a) Virtual scene, (b) Noise signal.

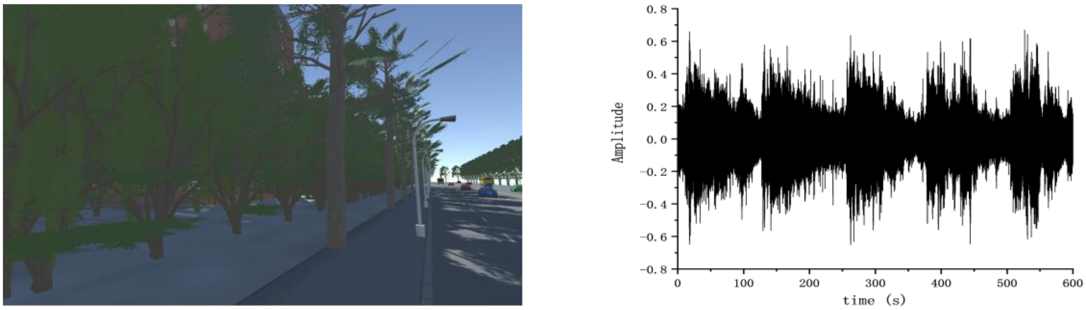

Figure 12: The fourth predetermined evaluation location: (a) Virtual scene, (b) Noise signal.

4 CONCLUSIONS

There has been an increased recognition that more attention needs to be paid to engineering education and vocational training for environmental impact assessment of noise pollution. With the rapid development of urban traffic networks, traffic noise pollution plays an important role in urban environment pollution and thus the propagation and attenuation of traffic noise in residential areas need to be learned by practitioners. Providing a vivid virtual environment for active learning based on historical or hypothetical cases, the combination of case-based learning and virtual reality stimulates trainees' interest in learning and significantly improves teaching quality. Nevertheless, the case generation for traffic noise propagation in urban residential areas is time-consuming, and the audio-visual association in the virtual environment of these teaching cases is challenging. The objective of this work is to propose a case generation system that produces intuitive and interactive teaching cases for the propagation of urban traffic noise in residential areas. The 3D scene is parametrically established for an urban residential area with surrounding traffic and noise reduction facilities based on virtual reality. Noise in the virtual scene is computed using noise mapping and then fed back into the scenes to associate the virtual scene with the noise environment and to synchronize scene roaming with noise experience, which forms a complete audio-visual teaching case.

An urban residential area in Beijing is selected for a case study. A corresponding virtual reality-based teaching case is programmatically built in the case generation system and noise distribution analysis is performed according to the computation for the residential area to evaluate the validity of the case generation system. Auditory perception based on roaming routes and predetermined evaluation locations distinguishes it from conventional teaching cases for noise impact assessment which describe case scenarios by descriptive texts and on-site photos and present the noise environment through the mapping of noise level indicator contours. Two examples of case-based learning about noise impact assessment, one on technical approaches and the other on technical guidelines and standards. demonstrate the promising potential of the proposed case generation system in case-based learning of noise impact assessment. Helping trainers parametrically establish virtual reality-based teaching cases which are a vivid complement to formula interpretation of noise propagation and data analysis based on noise exposure contour maps, the proposed case generation system is a powerful tool for engineering education and vocational training for environmental impact assessment.

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