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Research on the Reform of Architectural Acoustics Education Based on Noise Measurement and Simulation

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ABSTRACT

This paper aims to enhance students' comprehensive practical abilities in the field of architectural acoustics through teaching reforms, especially in terms of how to effectively apply acoustic knowledge to the entire process of site planning and architectural design. In response to the disconnect between theory and practice in traditional architectural physics courses, this paper proposes the introduction of a combined experimental teaching model that integrates field noise measurement and simulation. Through this model, students can not only master the basic theories and principles of architectural acoustics but also deeply understand the impact of noise on the functional quality and environmental quality of architectural spaces through on-site noise monitoring and digital simulation technologies. The course content covers noise control and management from the early stages of building planning, design optimization, to later stages of building renovation, with a focus on the application of architectural acoustic simulation techniques in practical design. This approach not only helps students improve their practical application of architectural acoustics knowledge but also cultivates their ability to address noise issues effectively during the design process, ultimately promoting the organic integration of architectural design and environmental sustainability. The teaching reform proposal put forward in this paper seeks to enhance students' ability to solve practical problems by combining theory and experimentation and provide theoretical and technical support for acoustic optimization in future architectural designs.

1. Introduction

With the increasing emphasis on the "human-centered" concept, architectural education and practice are increasingly focused on enhancing human life quality, particularly in terms of environmental comfort, health, and sustainability. In architectural design, traditional considerations such as aesthetics, functionality, and structure can no longer meet the comprehen-

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sive demands of modern society for built environments. Noise pollution, as a key factor influencing environmental quality, directly affects people's physical and mental health, work efficiency, and overall quality of life. This issue has become even more critical with the rapid urbanization process, where problems like traffic noise and construction noise have grown more severe. To address this challenge, effectively controlling and optimizing the noise environment in architectural design has become an important topic in modern architectural education. Architectural noise issues are not only a technical challenge but also involve the consideration of the overall performance of the built environment, including the organic integration of lighting, thermal, and acoustic environments. How to improve the comfort and sustainability of architectural spaces through rational design and technological means has become an indispensable part of modern architectural design education. In this process, the application of architectural environmental simulation technology has become increasingly essential in both teaching and practice. Particularly, the use of computer-based simulation and virtual reality technologies has provided students with more intuitive and precise tools for understanding architectural environments.

Several scholars have actively explored the application of architectural environmental simulation technologies. Hong, for example, introduced building performance simulation technology and utilized the Ladybug and Honeybee software platforms to optimize simulations of building energy consumption and lighting environments, aiming to cultivate students' ability to enhance environmental comfort through simulation techniques in architectural design [1]. Through simulation technology, students not only gain a deeper understanding of the basic principles of thermal and lighting environments in architecture but also effectively improve their practical application skills in actual design, thereby enhancing teaching effectiveness. Similarly, Bian Yu and others emphasize the importance of experimental teaching methods. They argue that through hands-on practice and personal experience, students can systematically master the knowledge of architectural optics, innovate lighting environment teaching models, and enhance their practical application abilities in lighting design [2]. In the field of architectural acoustics, Zhu Xiangdong used an experiential teaching approach and assessed students' understanding of architectural acoustics knowledge before and after the course through surveys. He found that this method effectively helped students establish foundational concepts in architectural acoustic design and improved their ability to solve practical acoustic problems in architectural design [3]. Shao Teng and others proposed a problem-oriented teaching model, incorporating research-based problem modules to encourage students to explore and analyze autonomously. This not only helped students better understand architectural acoustics theory but also strengthened their research capabilities. With modern technologies such as virtual simulation and performance simulations, students can understand and apply architectural acoustic design principles in realistic experimental environments [4]. Furthermore, Yue Siyang and Li Xinxin combined methods like soundscape, sound-walk, and subjective evaluation to design an outdoor sound environment experiment based on both objective and subjective analysis. This helped students gain a more intuitive understanding of environmental noise and realize that the sound environment is not only determined by the volume of noise but also closely related to the types and composition of sounds, which in turn produce different physiological effects. This experimental model strengthened students' comprehensive awareness of the impact of sound. Further innovation can be seen in the application of virtual simulation technology [5]. Li Lei et al. introduced a virtual simulation platform into acoustic experiments by integrating LabVIEW-based AD2 handheld labs and virtual reality (VR) technology. This allowed students to break through the constraints of experimental space and time, offering a more vivid and interactive learning experience. Virtual simulation technology not only breaks the limitations of experimental equipment and venues but also significantly reduces the difficulty of experimental operations, helping students better understand abstract acoustic concepts while enhancing their practical skills and innovative thinking. Additionally, the virtual simulation teaching model for environmental noise monitoring has made significant progress [6] [7]. Li Wenwen, through the reform practice of the virtual simulation experiment on environmental noise monitoring at Anhui Normal University, explored how to combine traditional teaching methods with modern simulation technologies. By implementing a progressive virtual simulation system, this approach enhances students' practical skills. This model overcomes the limitations of time and space, allowing students to gain a deeper understanding of the specific operations of noise monitoring without external environmental restrictions, and become more proficient in environmental noise analysis in real-world scenarios [8] [9]. The issue of campus noise has also received widespread attention. Huang and others used a noise propagation model to develop a noise map for university campuses, aiming to identify and analyze the campus noise environment. By adjusting the distance between buildings and traffic routes or adopting reasonable soundscape designs, noise interference with teaching activities can be effectively reduced, thereby improving the acoustic environment of the campus. This research provides feasible solutions for campus noise control and optimization, offering theoretical and practical support for future similar studies [10] [11].

Through the continuous advancement of these teaching innovations and practices, the environmental and acoustic education in architecture has gradually moved towards a more specialized and refined direction, particularly with significant breakthroughs in the application of modern technological methods. Methods such as virtual simulation, experiential teaching, and experimental learning have not only effectively enhanced students' practical abilities and innovative thinking but also provided new perspectives and tools for architectural design and environmental optimization. As these educational models continue to develop and improve, future architectural design is expected to achieve more intelligent and personalized advancements in areas such as noise control and environmental optimization.

2. The Significance of Integrating Noise Measurement and Simulation in Design

In modern urban environments, noise has become an environmental nuisance that cannot be overlooked. Although noise does not directly threaten life safety, its impact on human health is profound and long-lasting. Prolonged exposure to excessive noise levels can lead to hearing loss and is also closely associated with the occurrence of cardiovascular diseases. High-quality acoustic environments play a crucial role in enhancing the quality of life. However, the harmful effects of noise are often difficult to detect or ignore, and its negative impact is challenging to completely eliminate. Therefore, addressing noise control and simulation in architectural design is of paramount importance. This is particularly significant in architectural education, where the integration of noise measurement and simulation technologies plays a key role in enhancing students' understanding and practical skills.

Currently, many architectural schools focus heavily on fostering students' imaginative thinking and artistic creativity, often at the expense of emphasizing the application of architectural engineering techniques and the analysis of real-world environmental issues [12]. In the process of architectural design, noise is not merely a standalone design element; it is also closely related to factors such as the building's materials, structure, and layout. Traditional architectural acoustics experiments (e.g., measuring sound pressure levels, reverberation time, and sound absorption coefficients) provide students with fundamental data on noise control. However, these experiments are typically conducted in isolation, lacking a comprehensive understanding of the relationships between various architectural physical elements. Therefore, the integration of noise measurement and simulation can help students better grasp the holistic approach to architectural acoustics design during the learning process.

In simulation exercises, students are able to analyze the factors of noise propagation, building layout, material selection, and other elements in an integrated manner, developing a comprehensive understanding of the physical environment of buildings and enhancing their ability to address complex environmental issues. With the rapid development of information technology, modern tools such as virtual laboratories, virtual simulation systems, and immersive software have provided richer educational resources and methods for architectural teaching. These technologies can break the limitations of traditional teaching, offering students a more vivid and intuitive learning experience. Through virtual simulation, students can not only simulate noise propagation in buildings in real-time, but also directly experience the impact of noise on different spatial layouts and material configurations within a virtual environment. This immersive experience deepens students' understanding of noise control technologies, cultivating their ability to apply various technical solutions to solve environmental problems in actual architectural design, thus driving profound transformations in experimental teaching concepts, methods, and approaches in architectural education.

Future work for architecture students will not only involve creative design, but also addressing a variety of practical environmental challenges. Although current experimental teaching does not place particular emphasis on hands-on skill development, it does demand rigorous design capabilities and the ability to analyze and address environmental problems. Through the combination of noise measurement and simulation, students can not only master simple experimental methods and data processing techniques, but also enhance their sensitivity to environmental noise issues and cultivate comprehensive environmental analysis and problem-solving skills. Throughout the teaching process, experiential learning enables students to gradually establish foundational concepts in architectural acoustics design, understand the importance of noise control, and apply their knowledge in subsequent design practices to propose feasible solutions for environmental improvement.

With the growing promotion of green building and sustainable design concepts, noise control has become an indispensable aspect of architectural design. The integration of noise measurement and simulation allows students to approach the design process from a sustainable development perspective, considering how to minimize noise in architectural design while optimizing building structure, material selection, and layout to maximize the acoustic quality of both indoor and outdoor environments. Simulation not only helps students predict noise levels but also provides opportunities to compare and optimize various design solutions, promoting architectural designs that are more focused on ecological and human-centered needs, thereby enhancing the environmental friendliness and comfort of buildings. With the rapid development of virtual reality (VR) and artificial intelligence (AI) technologies, the combination of noise measurement and simulation has entered a new phase. Virtual reality technology offers an immersive learning experience, allowing students to personally experience the effects of noise control and simulate noise propagation under different design scenarios in a virtual environment. This immersive experience enhances students' understanding of noise issues and helps them make more precise judgments in design. Artificial intelligence, on the other hand, can optimize design solutions by analyzing large amounts of noise data, automatically adjusting building layouts and material configurations to achieve more effective noise control. The integration of VR and AI technologies into noise simulation not only increases the interactivity and scientific nature of architectural teaching but also drives architectural design toward more intelligent and personalized solutions.

In conclusion, integrating noise measurement and simulation into architectural education not only addresses the current shortcomings in practical training but also enhances students' design capabilities in noise control. Through modern information technology and innovative teaching methods, students are able to gain a more comprehensive and systematic understanding of the impact of noise on architectural design, improving their ability to solve environmental issues and laying the foundation for future sustainable and intelligent building designs. This innovation in teaching methods will inject new vitality into architectural education and promote further development in the architectural design industry, particularly in terms of environmental protection and human-centered care.

3. Environmental Noise Monitoring Experimental Teaching

3.1. Teaching Objectives

The goal is to help students deeply understand the relationship between noise sources and environmental factors, while developing their observation and analytical skills. Students can start by identifying major noise sources on campus, such as traffic, industrial activities, and crowd gatherings, while also considering how noise propagates in different environments, like open spaces versus enclosed areas. This analysis enables a deeper understanding of noise impact on the built environment.

During field measurements, students are encouraged to consider multiple perspectives, including but not limited to locations such as the boundary of the campus where it meets urban roads, and teaching buildings or dormitories near busy city streets. These areas may face substantial traffic or industrial noise, particularly during peak hours in the morning or evening. Allowing students to select their own measurement points helps them develop skills in choosing appropriate locations for measurements, avoiding blind spots, and considering how noise levels may vary at different times of day.

When using a sound level meter, students need to understand the basic principles of noise measurement, including how sound pressure levels (dB) are calculated and how to operate the sound level meter. By measuring noise at different locations, students can compare the noise levels across various points and analyze the noise distribution patterns through data analysis. This activity not only helps students master the techniques for noise data collection but also cultivates their ability to conduct systematic analysis, preparing them for future simulation modeling exercises.

3.2. Selection of Experimental Scope

In this experiment, the Wuhan University of Engineering (Wuchang Campus) (see Fig. 1) is selected as the experimental measurement area. Located in the center of Wuhan, the university has heavy traffic both within and around the campus, with a complex surrounding built environment, making it ideal for noise monitoring and analysis. Choosing this specific area not only helps students better understand the characteristics of noise propagation in different environments but also enhances their ability to identify and perceive real-world noise sources.

At the beginning of the experiment, a classroom discussion was guide students to share their understanding of noise sources based on their daily experiences and perceptions. This session aims to help students start from subjective experiences to understand the impact of noise in various environments. For example, students may mention traffic noise around classrooms, air conditioning noise inside teaching buildings, or noise from sports activities on the playground. These discussions provided initial directions for selecting subsequent monitoring points.

Based on students' feedback and perceptions, several representative monitoring points within the campus were selected for the experiment (Table 1). The selection of these points takes into account the diversity of noise sources while ensuring the comprehensiveness of the experiment. The selected points include, but are not limited to, the following environmental types:

1) Around teaching buildings: For example, areas near city roads. The main noise source in these areas comes from road traffic, and students can measure the intensity of traffic noise using sound level meters.
2) Physical barriers: These points are chosen to help students understand the characteristics of low-noise environments.
3) Student dormitories: Students are most sensitive to noise when resting.

During the selection of monitoring points, students use sound level meters and other common acoustic instruments for field measurements, converting their subjective perceptions of noise into objective, quantitative data. This process is an important practical exercise for students to understand the impact of noise on the environment and helps them develop their skills in using acoustic equipment. By regularly recording noise levels (such as A-weighted sound pressure levels) and conducting spectral analysis of the noise, students gradually grasp the basic characteristics and propagation patterns of noise.

Furthermore, the experiment involves the analysis and comparison of measurement data. Students not only need to understand the distribution of noise sources but also analyze how noise affects campus life through data analysis. For example, they can compare the differences in noise levels between various monitoring points to analyze the noise level differences between busy traffic areas and quiet zones, as well as the changes in noise pollution across different times of the day.

Through this practical exercise, students do not only perceive and understand noise in real environments but also transform these subjective insights into actionable, scientific engineering data. This helps cultivate their practical skills and sensitivity, which is valuable for future work in architectural acoustics design or noise control.

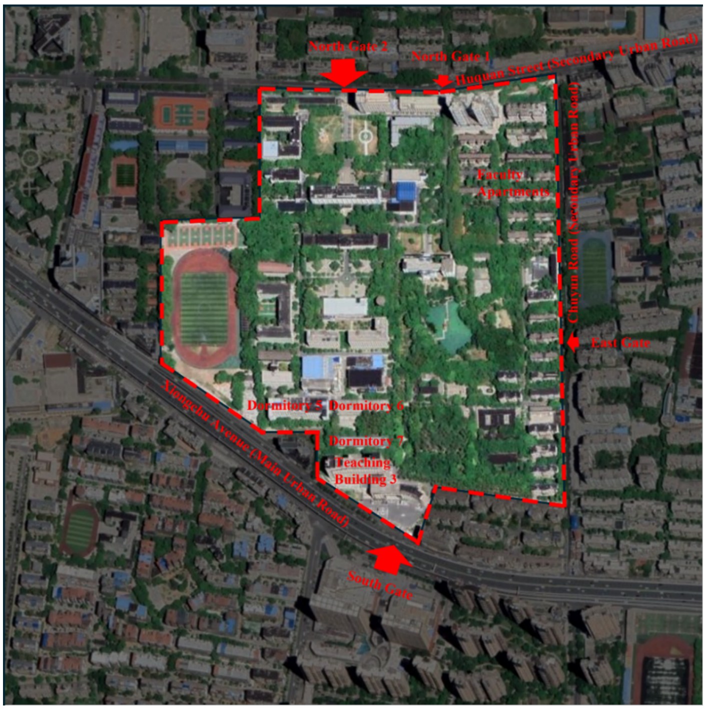


Figure 1 I Wuhan University of Engineering (Wuchang Campus)

Table 1| Description of Preset Measurement Locations

Measurement Location	Feature	Primary Noise Source	Other Preset Noise Sources
1-2	North boundary of the campus, adjacent to a secondary urban road	Traffic noise	Pedestrian noise
2-3	East boundary of the campus, adjacent to an urban secondary road	Traffic noise	Pedestrian noise, student play noise
3-4	South boundary of the campus, adjacent to a main urban road	Traffic noise	Pedestrian noise
A	North gate of the campus, varying building heights	Traffic noise	Pedestrian noise
B	East boundary of the campus, inside a physical barrier wall	Traffic noise	Pedestrian noise, student play noise
C	South boundary of the campus, 3rd teaching building at different heights (controlling open vs. closed windows)	Traffic noise	-
D	South boundary of the campus, 5th dormitory building at different heights (controlling open vs. closed windows)	Traffic noise	Pedestrian noise, student play noise
Random	Selected by students based on actual measurements, for comparative experiments	Student defined	Student defined

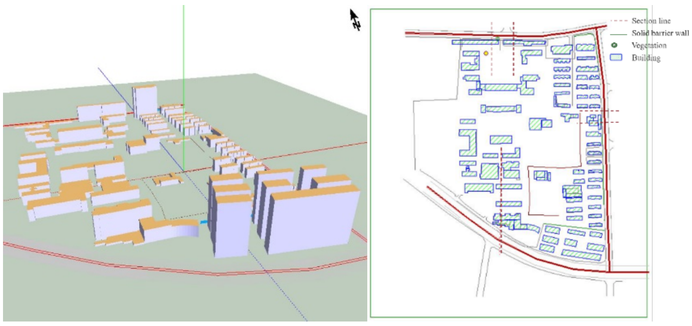


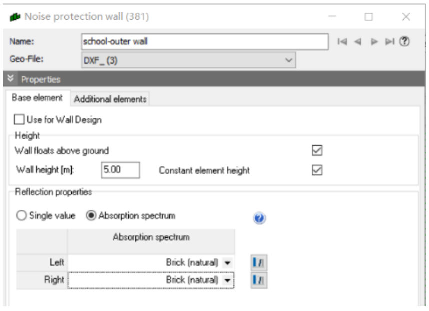
Figure 2 | Modeling of Wuhan University of Engineering (Wuchang Campus)

4. Simulation-Based Teaching With Environmental Noise Monitoring Data

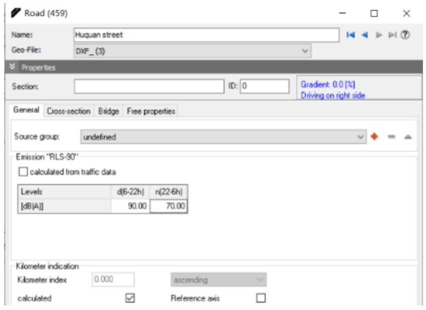
Students are introduced to advanced acoustic simulation technologies, gaining a deeper understanding of the complexity of architectural acoustic design. By using the SoundPLAN 8.2 acoustic simulation software to model the campus (see Fig. 2), students are able to convert actual measurement data into simulation parameters and import them into the model database. This allows them to simulate noise propagation and visualize the impact of different design solutions on noise levels. This process helps students integrate theory with practice, enabling more accurate calculations and predictions for noise control.

Teaching students how to input actual measurement data into simulation software (see Fig. 3) helps them understand the importance of each input parameter, such as noise source location, surrounding buildings, meteorological conditions, and more. Students must carefully input every parameter to ensure data accuracy, as even a small error could lead to deviations in the simulation results, which in turn could impact subsequent design decisions. Therefore, it is crucial to cultivate a rigorous experimental attitude in students, especially in architectural design, where overlooking details can lead to serious noise-related issues.

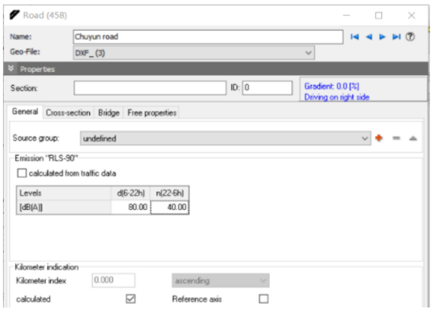
By displaying the simulation results, students will be able to observe the noise propagation paths, the noise level distribution across different areas, and the impact of building design on noise control. The simulation not only enhances students' technical skills but also strengthens their spatial thinking, helping them to more intuitively understand the relationship between architectural design and environmental factors.



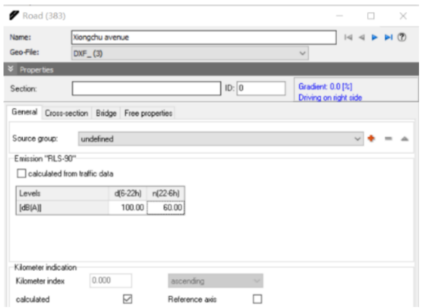
a) Parameters for the perimeter wall (also serving as a noise barrier) along the campus exterior on the urban road: Wall height is 5 meters, and the material is brick.



b) Noise parameters and road width settings interface for Huxian Street



c) Noise parameters and road width settings interface for Chuyun Road



d) Noise parameters and road width settings interface for Xiongchu Avenue

Figure 3 l Traffic Noise Source Parameter Settings

5. Teaching Design Strategies Based on Simulation Results

Based on the measurement data and simulation results, students will be required to propose specific noise control strategies. This process helps them apply the knowledge they have learned to real-world architectural design, thereby enhancing their design thinking and problem-solving abilities.

5.1. Planning Stage

During the site planning phase, students need to analyze areas within the campus that experience higher levels of noise (such as those near urban roads or busy traffic intersections) and reasonably lay out the functional areas of the building according to the noise distribution. For example, spaces that require quiet environments, such as dormitories and classrooms, should be located away from areas with higher noise levels to minimize the disturbance caused by noise.

The southern boundary, which is not shielded by any buildings, is directly exposed to external traffic sources (such as main roads), allowing noise to easily propagate along the southern edge and enter the campus. Due to the lack of effective sound barriers or building shielding, this side becomes a major source of noise. The sound waves travel directly into the campus, and especially low-frequency noise, which is not easily absorbed or attenuated by obstacles in the air, leads to significant noise disturbance. On the northern boundary, the presence of single-story and high-rise buildings reduces the impact of noise. In particular, the high-rise buildings, due to their greater height, provide a better sound barrier effect, effectively blocking external noise. High-rise building facades act as reflectors that can reflect or redistribute noise to surrounding areas, reducing the likelihood of noise entering the interior of the campus. However, noise intrusion at the northern gate remains relatively strong, likely due to the insufficient building shielding in that area, allowing noise to directly propagate into the region. To the east, the presence of solid walls provides relatively good sound insulation. Although the eastern boundary is near a city service road with lower traffic noise, the wall effectively limits the propagation of sound waves, keeping the noise disturbance in this area relatively low. The solid wall acts similarly to a sound barrier by increasing the path of sound propagation and energy loss, reducing the noise intrusion into the campus. In the northeast and southeast corners of the campus, near the road intersections, high-rise residential buildings serve as effective noise shields. These buildings reduce the propagation of traffic noise, especially in terms of low-frequency noise isolation, playing a crucial role in blocking unwanted sound. In architectural acoustics, high-rise residential buildings not only act as physical barriers but also alter the sound wave propagation path, reducing direct noise intrusion. The eastern part of the campus, primarily housing the faculty apartments, is relatively quiet according to simulation results. This area experiences lower noise levels due to the effective barriers provided by multi-story buildings and solid walls (see Fig. 5-a and 5-b). Additionally, the eastern area is far from the main roads and busy streets, which further helps in avoiding external noise interference. In contrast, the noise disturbance in the southern areas, such as in Teaching Building 3 (see Fig. 5-c) and Student Dormitory 5, is more significant. The noise is especially pronounced on the eastern side of Dormitory 5, where Dormitory 6 also experiences considerable noise impact. This is likely due to these buildings being located near noise sources (such as major roads or transportation hubs) and lacking adequate shielding or sound barriers. To improve noise isolation in these areas, acoustic barriers could be added, or the building facades could undergo soundproofing modifications (such as using sound-absorbing materials or thickening the walls) to reduce the intrusion of external noise.

Through this simulation analysis, it can be concluded that building design plays a crucial role in noise control within the campus. High-rise buildings and solid walls are effective in reducing the transmission of external noise, while low-rise buildings and areas lacking shielding are more susceptible to noise interference. For the southern boundary, the campus needs to consider adding noise barriers or taking other architectural acoustic measures to mitigate the impact of traffic noise. Additionally, for areas with more concentrated noise around the northern gate and the southern side, acoustic optimization designs could be considered, such as adding green belts, noise barriers, or sound-absorbing materials, to further reduce noise interference and improve the acoustic environment within the campus. It is also advisable to place buildings that require a quiet envi-

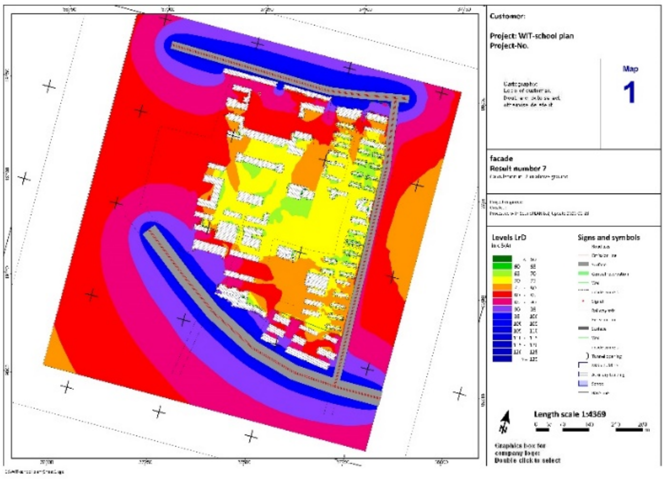


Figure 4 | Simulation Results for the Entire Campus (Affected by Traffic Noise)

a) Cross-sectional simulation results for the eastern boundary (with solid walls)

b) Cross-sectional simulation results for the eastern boundary (with solid walls and multi-story buildings parallel to the street)

c) Cross-sectional simulation results for the southern boundary (Right 1: High-rise building is Teaching Building 3; Right 2: Student Dormitory 7; Left 1: Student Dormitory 6; no solid wall)

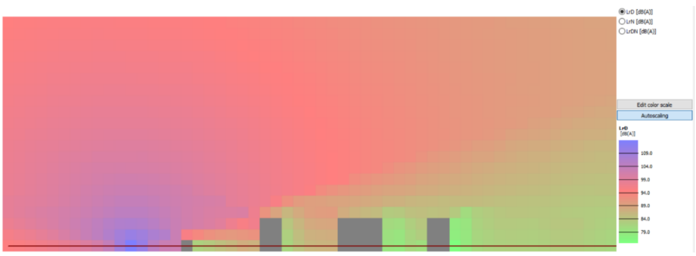
Figure 5 | Simulation Results for the Entire Campus (Affected by Traffic Noise)

ronment in areas further away from urban roads and busy streets.

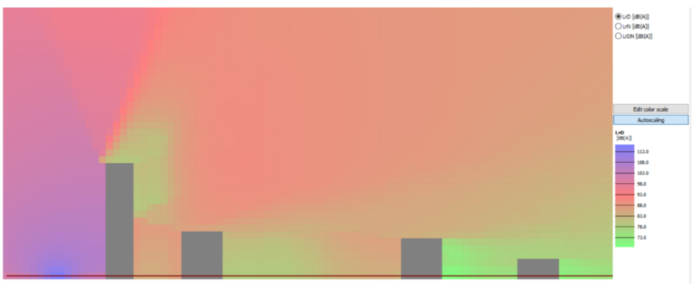
5.2. Design Stage

During the architectural design phase, students can propose noise control measures such as the use of soundproof materials and noise barriers. By modifying the design of the building's façade, improving the acoustic performance of windows, and refining the construction of the building envelope, the impact of external noise on the interior environment can be effectively reduced. At the same time, considering the building's external environment and surrounding traffic flow, the design of the building façade can be optimized through specific structural approaches to enhance noise reflection and absorption.

When analyzing the northern boundary of the campus (Fig. 6), the design of high-rise buildings offers significant acoustic advantages. The height of a building directly impacts its noise shielding effect. High-rise buildings typically increase the reflection path of noise, reducing the likelihood of noise transmission into the building. This is because the noise barrier effect of a building strengthens as its height increases, and the façade of a high-rise building can effectively block external noise sources, such as traffic noise. Acoustically, building height not only affects the propagation path of sound waves but also alters the pattern of sound wave distribution in space. Particularly in controlling low-frequency noise, high-rise buildings can effectively reduce the angle of incidence of noise by increasing the propagation distance and angle of sound waves, thereby mitigating the impact of noise on the building. In this scenario, the long sides of the buildings are oriented towards and parallel to the street.



a) Northern campus boundary (single-story building facing the street)



b) Northern campus boundary (high-rise building facing the street)

Fig. 6. Simulation cross-sectional results of the northern campus boundary (affected by traffic noise)

By using the building façade as a reflector, sound waves are reflected or dispersed to other areas, preventing noise from directly entering the interior of the building. Through this method, the building serves as a sound barrier in architectural acoustics, effectively blocking the impact of external traffic noise on the campus. In contrast, for single-story buildings, the relatively low height limits the reflection effect. The short façade of a single-story building cannot effectively reflect sound waves, and the intensity of reflected sound waves is weak. Furthermore, the sound barrier effect of a single-story building is insufficient to provide effective noise isolation. The reflection coefficient and soundproofing performance are generally strongly associated with the building's height and shape. Low-rise single-story buildings are less effective at reflecting high-intensity traffic noise, allowing noise to easily enter the building site.

As a result, students can clearly observe that high-rise buildings offer significant advantages in architectural acoustic design for noise control. By adjusting the building's height, shape, and material selection, noise can be effectively reflected, refracted, and absorbed. In contrast, single-story buildings, when facing external noise, require additional acoustic design measures to compensate for their limited soundproofing performance.

5.3. Renovation Stage

During the renovation phase, students can propose noise control measures for existing buildings on campus. Taking the street-facing sides of Building 3 (teaching building) and Buildings 5 and 6 (student dormitories) on the southern boundary as examples, noise interference inside the buildings can be reduced by adding window soundproof layers and double-glazed curtain walls. Additionally, adjustments to the external environment, such as the permeability of campus walls and vegetation types, can be explored to improve the acoustic environment through natural noise barriers.

6. Discussion and Conclusion

Due to factors such as wind speed, air humidity, and the varying sound absorption characteristics of different environmental elements (such as buildings and vegetation), the simulation results often show certain discrepancies with the measured data. This phenomenon helps cultivate students' ability to analyze and identify the acoustic characteristics of the environment and encourages them to apply these characteristics in practical planning and design.

At the current stage, teaching primarily relies on field measurements, aiming to equip students with the skills to operate common acoustic instruments, such as sound level meters, while also enhancing their awareness of the impact of noise in design. However, students in this process typically only have access to raw numerical data and tables, which may leave them at a theoretical level. To address this limitation, combining simulation results with field measurement data in a visual format allows students to more intuitively understand the path of noise propagation. This approach not only stimulates students' interest but also helps them build a more solid acoustic knowledge system, which provides greater depth compared to mere theoretical learning and data tables. Through this integration, students will be better equipped to accurately identify noise sources, assess noise impacts, and consider noise issues comprehensively based on both subjective and objective standards in their future work. This process will assist them in applying architectural acoustics principles more effectively in building design and site planning, thereby improving the environmental adaptability and comfort of their designs.

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