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Rethinking soundscape planning for an amphitheater in rainforest setting

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ABSTRACT

The quality of the acoustic environment plays a crucial role in shaping human communication and comfort within a space. This is particularly true for outdoor performance venues like amphitheaters. This study explores the potential of soundscape design to optimize acoustic comfort for audiences in the unique setting of a rainforest amphitheater. Rainforests, characterized by dense vegetation and uneven terrain, present both challenges and opportunities for acoustic design. While they may introduce unwanted background noise, the inherent properties of rainforest trees offer valuable potential for passive noise absorption. This research investigates how existing trees can be strategically integrated into the amphitheater design to utilize their natural sound-absorbing capabilities. The primary objective is to achieve a balanced soundscape that maximizes visitor comfort during performances. Initial findings suggest that strategically utilizing trees as noise buffers while preserving natural soundscape elements can be a viable approach. Furthermore, creating a diversity of dynamic sonic areas within the amphitheater appears promising in catering to individual preferences and enhancing overall acoustic comfort for the community. Ultimately, this study seeks a harmonious solution that optimizes performance acoustics for visitors while preserving the unique soundscape of the rainforest environment.

1. Introduction

Soundscape design, a concept pioneered by Porteous and Martin (1985), focuses on the aural environment and its impact on human perception within a specific location. It emphasizes the potential for careful planning, detailed site investigation, and design to shape the acoustic experience. Incorporating natural sound absorption is a key opportunity in soundscape planning, as highlighted by Kang and Schulte-Fortkamp (2014) in their work on soundscape and the built environment. The soundscape of a location is not simply a random collection of noises; it is a product of the space itself and the activities that occur within it. Hedfors (2003) highlights how the design, materials, and content of a space influence the sounds visitors hear and how they respond to their surroundings. These sounds, in turn, provide valuable information about the landscape and the activities that take place there, as Schroeder (1975) explored in his foundational work on architectural acoustics. Research by Yang et al. (2021) demonstrates the positive impact of natural sound sources on emotional regulation, pleasure, and perceived sound quality in outdoor spaces. This stands in stark contrast

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to the negative effects of traffic noise in public and urban environments. Further supporting this notion, Siaw Ling Lee et al. (2023) found a positive correlation between the perceived subjective well-being of park visitors and the presence of natural sounds. However, their well-being declined with increasing sound levels from human activity. This study explores the potential of soundscape design to optimize acoustic comfort for audiences within rainforest amphitheaters. We investigate the effectiveness of utilizing trees, specifically those belonging to the Dipterocarp family, as a tool for noise absorption and acoustic comfort enhancement. This research has two primary objectives:

1. Identify Effective Spatial Configurations for Soundscape Planning: We aim to determine the most effective spatial configurations for soundscape planning within open-air rainforest amphitheaters.
2. Evaluate the Effectiveness of Trees as Noise Absorption Tools: This research will assess the noise absorption properties of Dipterocarp trees and their potential to contribute to achieving optimal acoustic comfort within the amphitheater setting.

The findings of this study will provide valuable guidance for architects designing amphitheaters or performance centers in a rainforest setting. By leveraging the inherent sound-absorbing properties of trees as a passive noise control measure, this approach can promote the preservation and conservation of existing trees while enhancing the overall acoustic performance of the amphitheater. The significance of this research lies in its potential to improve both the spatial configuration of amphitheater design for optimal soundscape planning and acoustic performance. Furthermore, it will highlight the potential of specific tree species as a natural noise absorption tool, contributing to effective noise management and control within rainforest amphitheaters. This research focuses on the lowland Dipterocarp rainforest ecosystem, characterized by its diverse family of tropical hardwood trees. We will analyze the properties and sound absorption attributes of four specific Dipterocarp species to determine their efficacy in replacing traditional active noise control measures. Through a comprehensive study of existing trees and soundscape planning principles, this research aims to achieve optimal space environment quality with a focus on acoustic comfort by maximizing the use of passive noise absorption through the inherent properties of rainforest trees.

1.1 Literature review

Optimizing acoustic comfort in outdoor spaces like amphitheaters presents a unique challenge. While architectural design plays a crucial role, another often-overlooked element is the soundscape – the aural environment encompassing both natural and human-made sounds. Understanding how soundscapes influence human perception and experience is essential for creating comfortable and engaging outdoor spaces.

Soundscapes and Perception: Our perception of sound is significantly influenced by its interaction with the surrounding environment. Natural soundscapes, with elements like birdsong and rustling leaves, can be calming and restorative, promoting feelings of well-being and connection with nature (Watts et al., 2013). Conversely, excessive noise pollution can be detrimental to health and well-being, causing annoyance and hindering concentration (Viollon et al., 2002).

Visual-Auditory Interactions: Visual elements of space play a surprising role in how we perceive sounds. Studies have shown that greener environments can make even human-made noises seem less bothersome (Aylor & Marks, 1976). This suggests a crucial role for visual design, such as landscaping, in creating a harmonious soundscape within an amphitheater.

Strategies for Acoustic Comfort: Several strategies can be employed to enhance acoustic comfort in outdoor spaces. These include manipulating sound reflection through architectural features (e.g., stage enclosures), strategically planting trees for sound absorption (Alvarsson et al., 2010), and using natural materials for seating (like wood or bamboo) to manage reverberation time.

1.2 Materials and methods

This research utilizes a two-step approach. First, a systematic literature review will be conducted across databases like Web of Science and Scopus. We will search for relevant studies on soundscape design, rainforest acoustics, and vegetation's role in noise absorption. This review will establish a theoretical foundation for the second stage – a case study of a specific rainforest amphitheater. The case study will involve sound pressure level measurements, vegetation analysis, and visitor surveys to understand the existing soundscape, vegetation characteristics, and visitor preferences for acoustic comfort. By combining the broad knowledge from the literature review with the in-depth exploration of the case study, this research aims to achieve a holistic understanding of soundscape design for optimizing acoustic comfort in rainforest amphitheaters. The first stage of this research involves a comprehensive systematic literature review. This review aims to identify and critically analyze existing research on soundscape design, rainforest acoustics, and the use of vegetation for noise absorption.

- *Database Selection*: We will search relevant academic databases such as Web of Science, Scopus, and Google Scholar. Additional discipline-specific databases relevant to acoustics and landscape architecture may also be included.
- *Search Strategy*: A comprehensive search string will be developed using keywords related to soundscape design, rainforest acoustics, vegetation and noise absorption, and amphitheaters. This search string will be adapted and refined based on the specific capabilities of each database.
- *Inclusion and Exclusion Criteria*: Clear criteria will be established for selecting relevant studies. These criteria will consider factors such as publication date, peer-review status, and methodological rigor. Studies that do not directly address the research questions or fall outside the scope of the research will be excluded.
- *Data Extraction and Analysis*: Extracted data from the selected studies will be categorized and analyzed thematically. The review will synthesize the findings from existing research to provide a strong foundation for the case study portion of the investigation.

2. Case study

The second stage of this research involves a case study of a specific rainforest amphitheater. The case study will allow for an in-depth exploration of the soundscape within the amphitheater setting and the potential application of soundscape design principles for acoustic comfort optimization.

i. Soundwalk- Soundwalk and interviews are quite common in soundscape studies since they include participants' perceptions in the assessment. Soundwalk is chosen for the method of this study are the component to analyze the nature of sounds. The application from Apple Store, dB Meter is used to record decibels for each point marked.
ii. Hermeneutic Phenomenology - Individuals in continuous interaction with the location participate in getting their experience and perceptions which is significant to the study. This method represents a subjective story that contributes to the essence of the case studies. The relations between the individual and their social, economic, and cultural contexts are significant concerns for the approach.

There are 15 articles written in English and published from 2005 until 2021 on soundscape planning and acoustic comfort in outdoor settings being reviewed and analyzed in Table 1.

2.1 Case study 1: Panggung Udara Kuching

Panggung Udara Kuching, see Figure 1, was selected as the case study for this research due to the typology of a performance space and the environment that is surrounded by vegetation in the urban context. The 3-acre park consists of an open stage with a control room on the lower ground and a seating area for 1000 seats. The site is located approximately 2 km from Kuching Waterfront, the famous landmark in Kuching. For daily usage, the amphitheater is open to the public for activities such as jogging, and group exercises such as Zumba, tai chi, and yoga. The loop around the amphitheater is approximately 500m with a gradient of 1:4 from the highest to the lowest point which is the stage area.

2.2 Case study 2: Persada Alam

Persada Alam, see Figure 2, was selected due to its function and the surrounding which is surrounded by vegetation. Most species a dipterocarp species of a low land rainforest species of trees. Persada Alam is in Sarawak Cultural Village, Santubong as the main performance area for an annual event, the Sarawak Rainforest Music Festival held every year since 1998 with participants up to 10,000 participants in 2019. The 1.5-acre park consists of 2 covered stages and an open area for the viewer. The performance area was located 500m from the main entrance of Sarawak Cultural Village. Another significant feature that helps in the case study is the existence of a man-made lake located 50m from the seating area.

2.3 Soundwalk

2.3.1 Case study 1 – Panggung Udara Kuching

The sound walk was held by 2 batches see Figures 4 and 5 for sound level, at 7.00 am with 3 participants, the regular visitor doing their tai chi and 5 km jogging, and in the late afternoon at 5.30 pm with 3 participants who are the regular visitor of the amphitheater who came for 5 km jogging. The participants make a round of 500 m soundwalk, see Figure 3, with an average of 15 minutes with an intervals at marked points to process their acoustic comfort. The reading of decibels was taken at each point to record the level of sound during the interval. Questions were asked after participants stepped on 4 marked points. Question 1 asked at point A until point D is, how would you describe the sound? Question 2 what do you like about the sound of this location? Question 3 what do you not like about the sound at this location? Question 4 is rating the sound of this location, with +2 as highly appealing, 0 as neutral, and -2 as not appealing. After they finished their round, 4 general questions were asked. Question 1 is what is the loudest sound you heard in the park today? Question 2 is the most distant sound you heard in the park today? Question 3 what is your favorite sound you heard today? And question 4 is what is your least favorite sound you heard today?

2.3.2 Case study 2 – Persada Alam

The soundwalk was held at 1.00 pm with 3 participants. See Figure 7 for sound level, Participants are the regular Rainforest World Music Festival participants, chosen due to their familiarity with the audio and visual aspects of the surroundings. There are 4 points marked on site (Figure 16) with every stop, participants will be asked questions while taking the decibel meter at each stop. Question 1 asked at point A until point D is, how would you describe the sound? Question 2 what do you like about the sound of this location? Question 3 what do you not like about the sound at this location? Question 4 is rating the sound of this location, with +2 as highly appealing, 0 as neutral, and -2 as not appealing. After they finished their round, 4 general questions were asked. Question 1 is what is the loudest sound you heard in the park today? Question 2 is the most distant sound you heard on the site today? Question 3 what is your favorite sound you heard today? And question 4 is what is your least favorite sound you heard today? With the current situation of pandemics, the answer to this soundwalk questionnaire for this site had to be based on their experience during the Rainforest World Music Festival.

2.4 Hermeneutic Phenomenology

2.4.1 Case study 1- Panggung Udara Kuching

Questions were asked after participants stepped on 4 marked points. Question 1 asked at point A until point D is, how would you describe the sound? Question 2 what do you like about the sound of this location? Question 3 what do you not like about the sound at this location? Question 4 is rating the sound of this location, with +2 as highly appealing, 0 as neutral, and -2 as not appealing. After they finished their round, 4 general questions were asked. Question 1 is what is the loudest sound you heard in the park today? Question 2 is the most distant sound you heard in the park today? Question 3 what is your favorite sound you heard today? And question 4 is what is your least favorite sound you heard today?

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Table 1: List of studies in the systematic review in chronological order of publication. The research approach, methodology, location and were reported. The studies include soundscape planning approach, human acoustic comfort, and conclusion. For more specific information, it is possible to refer to the original studies

No.	Author	Research Approach	Methodology	Location	Soundscape Planning	Human Acoustic Comfort	Conclusion
01	Williams, Kenya DuBois (2021)	Soundscape planning	Hermeneutic Phenomenology Soundwalk Data collection	Tom McCall Waterfront Park in Portland, Oregon	A mixture of natural sounds combined with human chatter and vehicle noise.	Balanced soundscape for the public to obtain the best experience visiting the park.	A sonorous ensemble can be balanced by enhancing some aspects of the soundscape so that it offers a diversity of dynamic areas for a variety of communities to experience the soundscape.
02	Giggey, Brian Clayton (2010)	Soundscape planning	Soundscape planning research Case studies Program specification of amphitheater design	Holyoke, Massachusetts	Sound travels well within the site due to the trees surrounding it, high-velocity winds being stopped from passing through it, and the significant elevation changes.	The key determinant for sound attenuation is the landform and vegetative buffers between the source and the listener.	Enhanced acoustics within the site and surroundings offer a place of refuge for the visitor.
03	Brown, A.L. & Muhar, A. (2007)	Acoustic design	Literature review	Outdoor space	A need to educate designers and managers of open spaces about the importance and possibility of including the acoustic environment as part of the planning process.	Using natural and semi-natural scenes improves the quality of built-up environments.	Acoustic design can encompass strategies for dealing with noise concerns in cities and rural areas.
04	Brown, A.L, Gjestland, T. & Dubois, D. (2015)	Acoustic environment and soundscapes	Literature review	Built environment	With environmental noise management, sound quality, human acoustic comfort, and music, all acoustic contexts are of interest.	The outcome of a human perceptual construct of a place's auditory environment is greatly dependent on context.	The goal of soundscapes is to manage the auditory environment as a resource that improves human quality of life.
05	Wei Yang & Jian Kang (2005)	Soundscape planning	Case study Soundwalk Data collection	Peace Gardens, Sheffield (Urban square with water fountain)	Water and foliage improved soundscape quality by 79.3% keeping the flow rate constant.	As people get older, they become more tolerant of sound from nature, culture, and human activity.	For a defined space, the soundscape's identity is crucial since a more aesthetically appealing soundscape will attract more visitors.
06	Jaszczak, A., Małkowska, N., Kristianova, et al. (2021)	Soundscape planning	Case study Soundwalk Data collection	Parks in Olsztyn, Poland	The density of vegetation (compact trees or hedge forms) concerns the potential for noise reduction and noise attenuation.	The diversity of forms and species of plants affects the psychological perception of soundscape by visitors.	Visual and sound perception of parks relates to the psychological point of view of park users.
07	Yang, T., Aletta, F., & Kang, J. (2021).	Acoustic environment	Literature review	Large public buildings	The design of large buildings should focus on the performance of background noise level and sound reverberation.	The integrated design of indoor soundscapes can provide acoustic comfort for various building types.	Visitor perceptions were mostly based on sound contexts rather than sound levels.
08	Van Renterghem, T. (2019).	Acoustic interaction	Literature review	Courtyard with vegetation surrounding	Physical road traffic noise reduction is being reduced by building a vegetation belt as soundscape planning.	The environment is perceived as more positive with the presence of vegetation.	The reduction in visible green from the home in terms of nuisance could be as high as 10 dBA.
09	Krzywicka, P., Byrka, K. (2017)	Acoustic environment	Visual stimuli Hyperacusis questionnaire	University outdoor compound	Balanced artificial and natural soundscape planning in the study area.	Sound from the source of nature induces soft fascination as compared to urban sounds that evoke hard-to-listener	Natural soundscape within urban surroundings plays a role in well-planned soundscape planning.
10	Maichi C., Yu Peng, et al (2021)	Acoustic environment	Field survey Questionnaire	Zhuquan Village, China	Soundscapes are dominated by natural sound which brings a hi-fi and quiet sound environment with rich natural sound that can be heard from a longer distance.	Natural sounds emitted by the earth, vegetation, and animals make the rural landscape quieter.	Control all kinds of mechanical noise sources that invade rural landscapes to keep the hi-fi rural soundscape.
11	Alsina-Pagès, R., Ginovart-Panisello, G., Freixes, et al (2021)	Soundscape research	Case studies Soundwalk Data collection by the Hush City App	Poblenou Superblock, Barcelona	To construct a predictive model of perceived effective quality, soundscape descriptors are used.	Urban soundscape characterized by sound marks and perception varies from preference judgment	The acoustic measurement from technicians is to be included in methods of capturing acoustic comfort in soundscape for future design.
12	Qiu, M., Sha, J., & Utomo, S. (2020).	Natural soundscape and health	Case studies Analytical strategies Measurement	Burleigh Heads National Park, Australia	The soundscape of the forest is a natural soundscape with environmental admission from policymakers and managers.	In light of the current global health problem, the natural soundscape is critical. It does not necessitate physical touch and allows for social distance to be maintained.	Managers and policymakers to consider the importance of protecting natural soundscape.
13	Fang, X.; Gao, T.; Hedblom, M (2021)	Soundscape	Case studies Field Survey Questionnaire Data analysis	Parks in Xian, China	Social, demographic, and behavioral contributions to the parameter of soundscape planning	Personal differences influence the perception and preferences of the individual.	Human-centered soundscape design improves people's health.
14	Mancini, S., Mascolo, A., Graziuso, G., & Guarnaccia, C. (2021).	Soundscape	Literature review Soundwalk Data collection	University of Salerno, Italy	Areas with natural vegetation leave good soundscape preferences, while the presence of buildings and cars leaves an unpleasant soundscape.	The presence of the natural environment positively influences good acoustic comfort perception	The visual base design of a place affects people's perceptions. The visual and acoustic environment should be integrated for a holistic understanding of soundscape.
15	Turner A, Fischer M, Tzanopoulos J (2018)	Acoustic environment	Recording method Data analysis	Thetford Forest	Forest with diverse vocal resources has higher acoustic diversity. The balance between anthrophony and biophonic affects acoustic tranquility in managing and mitigating noise disturbance.	Humans have been proven to recover faster from stress when exposed to natural sound.	Landscape planning and noise mitigation measures can be accomplished using species distribution data.

Figure 1. Panoramic view of Panggung Udara Kuching

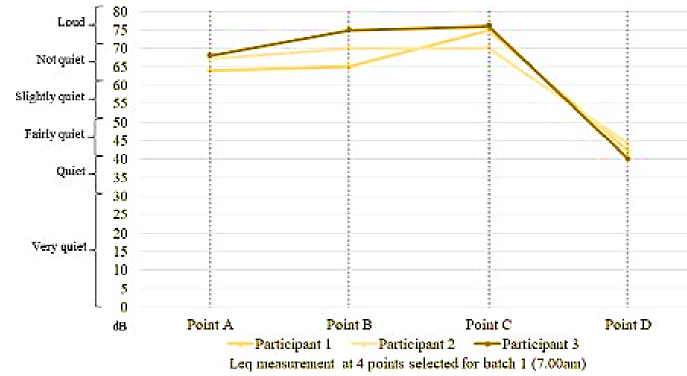

Figure 4. Graph table of Leq measurement at points for batch 1

Figure 2. Performance Stage at Persada Alam

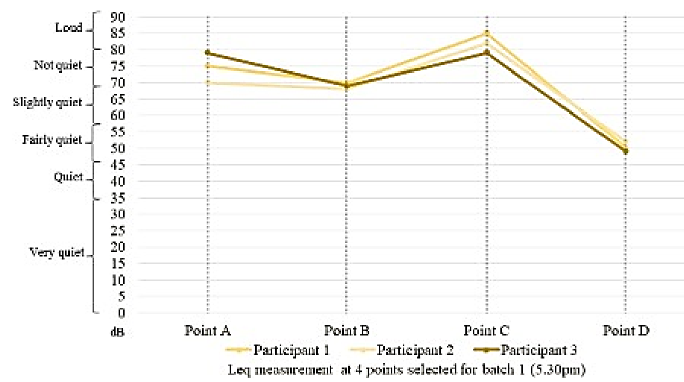

Figure 5. Graph table of Leq measurement at points for batch 2

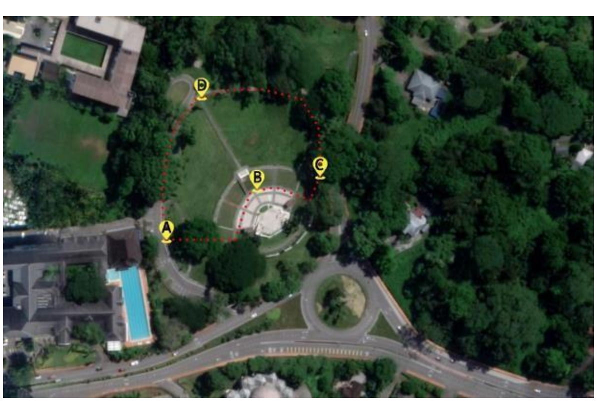

Figure 3. Plan view of Panggung Udara Kuching with soundwalk path route

Figure 6. Plan view of *Persada Alam*, *Santubong* with soundwalk path route

.

Table 2. Leq measurement at 4 points selected for batch 2 (5.30 pm)

Participants	Point A (dBA)	Point B (dBA)	Point C (dBA)	Point D (dBA)
Participants 1	75	70	85	50
Participants 2	70	68	82	52
Participants 3	79	69	79	49

Table4. Leq measurement at 4 points (1.00 pm)

Participants	Point A (dBA)	Point B (dBA)	Point C (dBA)	Point D (dBA)
Participants 1	75	54	68	65
Participants 2	72	59	65	69
Participants 3	70	57	68	67

Table 3. Participants' perception of associated visual images of soundscape

Point	Sound types	Direct pictures	Feeling and recollection	Activity	Evaluation
A, B, C	Anthrophony	Music from visitors exercising.	Good fun, ecstatic	People exercising with the music, people talking	Energetic, youthful, slightly noisy
C, D	Biophony	Birds, crickets	Harmonious, comfort	Birds chirping	Harmony
C, D	Geophony	Leaves rattling	Chilled, quiet	Wind	Tranquility, discreet

Table 5. Participants' perception of associated visual images of soundscape

Point	Sound types	Direct pictures	Feeling and recollection	Activities	Evaluation
A, B	Anthrophonies	Music	Good fun, ecstatic	Music from the stage, people talking	Energetic, youthful, slightly noisy
A, B, C, D	Biophony	Birds, crickets	Harmonious, comfort	Birds chirping	Harmony
C, D	Geophony	Leafs rattling, water	Chilled, quiet	Wind, water from the lake	Tranquility, discreet

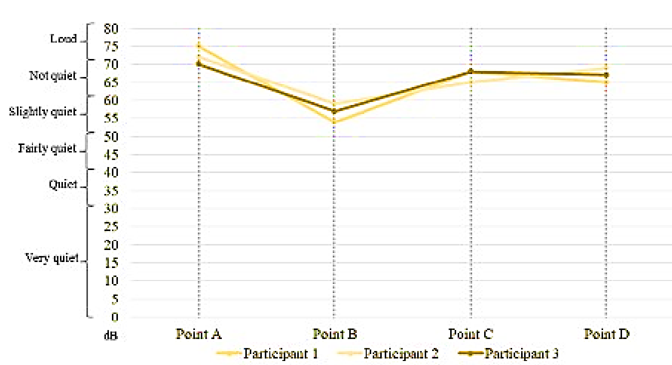

Figure 7. Graph table of Leq measurement at 4 points *(Persada Alam)*
Table 4: Leq measurement at 4 points (1.00 pm)

3. Results and discussion

The objectives of the study are to explore the outdoor performance space in a rainforest setting. In doing so, a literature study of an amphitheater and outdoor performance space design principles, materials, and guidelines on designing an outdoor performance space. The next objective is to use vegetation as the soundscape management tool instead of mechanical tools. In Malaysia, most species that occupy its forest are the low-land dipterocarp species of trees. Therefore, the species of trees at the case studies sites are being identified and research on their effectivity towards sound on the outlook and properties of its noise attenuation.

3.1 Spatial configuration of an outdoor amphitheater

In designing an amphitheater, the process of schematic design phases until completion is the same as other building typologies. The slight addition is during the schematic design phase which is the extensive research and study in soundscape planning. This is due to the function of the space focusing on the acoustic comfort of the visitor. Performance spaces such as opera houses, theatres, and concert halls have been the testing subject in comparing the acoustic design solutions and innovations be it in the material, seating arrangement, and layout of the spaces for the enhancement of human acoustic comfort as par with the visual aesthetic. Following the acoustic comfort requirement, the standard of ISO 3382 was released in 1975 to standardize the measurement of reverberation time. In understanding acoustic design, one shall start with the fundamentals including the history of architectural acoustic, physical concepts, human perception, acoustic measurement, and environmental noise. The main goal of architectural acoustic is a gathering space with maximum speech, music, and audio performance. It must provide the optimum acoustic comfort to the visitor and at the same time attenuate sound so that it is pleasing to be heard. The acoustic properties of the open-air theater or amphitheater were developed and emerged from the historical development of ancient open-air theater which goes back to the 6th century BC when the evolution of open-air theater emerged in Greece and Rome. The acoustic design of performance space must be seen as complementary to noise management, noise abatement, and noise control. The first step in configuring the spatial design of an outdoor performance space is to establish the activities and the scale of activity and user so that appropriate space and acoustic comfort can be configured. The next step is to compartmentalize the proposed acoustic environment, for performance space, the visitor's acoustic comfort varies, and with compartmentalizing the acoustic zoning, everyone can opt for the zone that suits their acoustic comfort. The scenario can be seen as a group of youth and a group of adults going to a musical event like a music festival or concert. The group of youth is prone to be nearer to the sound source as it enhances their feeling, and the noise gives them a good feeling instead of unease. As for the group of adults, they might choose to be a bit further from the source but are still able to grasp the sound that hits their acoustic comfort. The third step is to identify the wanted and unwanted sounds at the site. For this step, a site inspection is crucial in the schematic design phase to familiarize with the sound available at the site. While doing so, a soundwalk method can be practiced in enquiring for the information along with the site. This has been the starting point in breaking down the acoustic complexity of most sites to individual sound control approaches and management strategies. The first step is to figure out what activities will be held at the potential location. It is possible that zoning for acoustic settings will not be compatible with zoning for other purposes, in which case new zones will need to be created because of the overlap. The second step is to establish Proposed Acoustic Environments for each zone. Acoustic objectives are being put forward in the form of "the LAeq,1h of the site should be less than 55dB", or as tenuous concepts such as "the site should be quiet and relaxing"). The third phase entails determining which sounds are desired and which are undesirable at the location. This covers sounds that are now present at a location, as well as those that will be there once the proposed design or management is implemented. The loudness, time variation, and other acoustical features of each of the desired and undesired sounds in the current circumstance must be measured or assessed separately in the fourth stage. In the fifth step, design alternatives for managing either desired or undesired sounds, or both, must be considered to create the Proposed Acoustic Environment. This may entail employing normal noise management techniques to eliminate or control undesired sounds, or sustaining, augmenting, or producing desired sounds. For an outdoor performance space, noise control often seems to be ignored as they always rely on the mechanical system by the audio system to fix the noise decay or none. The outdoor theatre should be made compact and intimate as a technical and artistic need. The performance space needs to be enclosed while the sides can be open. If the performance space has no backdrop, planting monotonous and massive trees helps to attenuate sound from refracting to the back. The gradient of the seating as seen from the ancient open-air theater is an example of the effectiveness of noise control. The seating areas occupy the vast area in the performing space with a slight gradient of 2% - 5%, it is generally being kept at below 5% to avoid obstruction to access each seating. The gradient of not less than 5% is to avoid reflection from the stage blocked by the first row. To maintain the reverberation time, the seating material shall be coefficient with absorption properties. Therefore, for an outdoor amphitheater, materials such as wood are ideal, they have far less absorption.

Orientation is critical when building an outdoor performing area. If the performance space is used at night, which it is in most cases, it can have nearly any orientation. The worst configuration is when the theater's principal axis runs east-west and the audience is seated on the eastern end looking westward. The afternoon sun shines straight into their eyes in this configuration, whereas the other configuration shines directly into the actors' eyes in the other arrangement. As a result, an outdoor amphitheater should be built along a north-south axis. Natural factors such as terrain, of course, play a role in how a performance space is orientated.

3.2 Rainforest trees as soundscape management tool

In designing an outdoor performing space, along with the soundscape planning, the vegetation available around the site can be studied and identified. This is about the chances of using vegetation as a significant feature for noise attenuation. Based on the systematic review analysis, vegetation is highly preferred as a noise buffer for outdoor space as it helps in attenuating noise. Each plant demonstrates a specific noise reduction spectrum because the size of the foliage, trunk, branches, and belts varies from each other. However, the fact that trees can attenuate sounds is nonetheless proven due to their properties and characteristics.Vegetation in general can attenuate sound by reflecting, refracting, and absorbing it. Noise can be directly attenuated by foliage, stems, and soil, which act as a sound barrier for the tree. With factors such as the height of the tree, the size and density of trees, and the atmosphere of the forest, certain species of vegetation would be better at attenuating sound than others. Based on research by Fang and Ling (2005) the finding was that the species' leaf shape and leaf tactility may affect foliage's ability to achieve noise attenuation. With the properties and characteristics of vegetation in noise attenuation, architects and landscape architects have started to introduce vegetation as noise buffer tools for acoustic management. It was proven in the study by A.L. Brown & Andreas Muhar (2007) that the potential of capturing the acoustic design in managing noise pollution. There is also research made by Van Renterghem (2019) that concludes the level of reduction by vegetation belt could reach 10 Dba. In a further study, Li et al. (2020) used an impedance tube methodology to conclude that sound absorption is further enhanced by the bark's roughness, moss cover, and trunk width. In addition, conifers appear to have superior soundwave absorption (Li et al., 2020). Normal attenuation and excess attenuation are the two types of noise attenuation. Normal attenuation is induced by spherical divergence and air absorption, according to Embelton 1996. Any obstruction between the noise source and the receiver (barriers, ground, plants, trees, hills, etc.) causes further attenuation due to reflection, refraction, scattering, and absorption effects. The biomass of the stand, the structure of the stand in the horizontal plane (the size and form of the canopy), and the quality of the surfaces are among these characteristics (size and shape of leaves and needles, soil). Mixed stands of coniferous and deciduous trees are allowed to be admitted using these standards. Trees with greater foliage cover and large leaf surface areas have noise attenuation between 5-10dB in impedance tube analysis by S M et al. (2021).Dipterocarps can grow to be quite enormous and tall, and they make up a significant section of the rainforest canopy in Peninsular Malaysia. Dipterocarps make up to 57 percent of the emergent layer of Peninsular Malaysia's lowland forest, according to recent research. Dipterocarps make up much more of the emergent and canopy layer in Sarawak, accounting for 75 percent, while it can reach 90 percent in Sabah. The emergent in dipterocarp forests tend to congregate in groups. This means that emergent trees are commonly found in small groups rather than as individuals, and since dipterocarps make up such a large portion of the emergent layer, this may be a tendency of dipterocarps in primary forests. Generally, in North Borneo, they regularly attain heights of 60-70+m, with some in the 80-90m range in Eastern Sabah. With the properties of Dipterocarp tree species which are large, they can grow up until 60m. The bole is greenish grey with yellowish-brown patches. The bark surfaces are lenticular and later fall to the ground in scales. The branches are slender and dense with the bud tapering and densely clothed with soft hair. Most Dipterocarp trees come with fruits that are hairy and winged. With its foliage rather open and spherical crown with unbuttressed roots. The specific characteristic of dipterocarp species especially the fact that they are often in the group helps in revisiting the soundscape for the environment.

3.3 Human Acoustic Comfort in Nature Setting

When it comes to how humans interpret their surroundings, audio-visual interactions are crucial. Visible, high-quality natural features resulted in sustained attention restoration and stress alleviation, mitigating the harmful effects of prolonged environmental noise exposure. Natural sounds, particularly bird songs, are relaxing and they promote nature's restorative function by implying close and vital nature. Traditionally, the effectiveness of noise pollution abatement has been measured in terms of sound pressure level reduction. However, according to Fritschi (2011), one of the biggest health effects is noise irritation, which is not solely tied to physical noise indicators. According to research, the sound pressure level accounts for just 30% of the variance in self-reported noise irritation. Noise discomfort is the outcome of intricate cognitive processes that are influenced by a variety of acoustic, environmental, and personal factors. When humans perceive the environment, which is fundamentally a multi-sensory process, audio-visual interactions play a key role.Watts et al. explored a variety of perception-related variables in the literature that dealt with the relationship between vegetation and noise perception, including loudness. In general, it is thought that a quieter, calming, or pleasant environment, or one that is less noisy, is less unpleasant. Much research has revealed that visuals have a significant impact on auditory judgment, even when source (in)visibility is not considered as a possible explanatory factor. Visual settings with flora and natural elements appear to have a positive impact on the appreciation of sound environments.According to Viollon et al. (2002), all noises except human noises were thought to be less pleasurable or stressful. When the visual stimuli became more urbanized. In their experiment, urbanization is characterized as opposed to natural landscapes. This is true for audio-visuals that are both congruent and incongruent. In a greener atmosphere, natural sounds can be produced by vegetative characteristics of sufficient scale, either by attracting or serving as a habitat for live species that create sounds (bird songs/calls) or by making noises that are inherent to their structure (rustling of leaves). Water sounds are the third kind of natural sound that has received a lot of attention and are typically encountered in plant-filled areas.The findings of Pheasant et al. (2008), Alvarsson et al. (2010), and Krzywicka and Byrka (2017). According to the studies, natural noises without visual stimulation are already relaxing and have healing potential. They discovered that the recovery physiologically of sympathetic is faster when exposed to pleasantly rated nature sounds. Overall, it is reasonable to hypothesize that the perception of the green has a greater influence at higher sound pressure levels than at lower sound pressure levels from road activity. Despite this, significant positive effects are expected across a wide range of environmental sound pressure levels. The investigations of source visibility concerning green show that audio-visual interactions are more intense at high sound pressure levels. The visual setting produced the largest effects near 75 dB in Aylor and Marks's (1976) experiment. The visuals, however, had no influence on loudness perception at the extremes (40 dB and 90 dB).Human comfort in a nature setting ensemble can be balanced by enhancing some aspects of the soundscape over others so that it offers a diversity of dynamic areas for a variety of community members to experience the soundscape and enhance their acoustic comfort. The findings of this research hold significant value for various stakeholders as follows:

1. Strategic Vegetation Integration: The case study revealed that strategically integrating existing rainforest trees, particularly those with dense foliage, can effectively contribute to noise absorption and improve acoustic comfort within the amphitheater. This finding suggests that architects and landscape designers can leverage the inherent sound-absorbing properties of rainforest vegetation during the design and construction of amphitheaters. By minimizing the need for additional soundproofing materials, this approach can promote sustainability and preserve the natural character of the rainforest environment.

2. Balancing Natural Soundscape with Performance Acoustics: The research underscores the importance of achieving a balance between the natural soundscape of the rainforest and the acoustic requirements for optimal performance clarity. While some natural sounds, like rustling leaves, can contribute to a positive immersive experience, excessive noise can disrupt performances. The findings suggest that soundscape design principles can be used to create diverse sonic zones within the amphitheater. This would allow for areas with a focus on natural sounds for pre-show ambiance and areas with enhanced acoustic control for performances.

3. Informing Future Research: This study opens doors for further exploration in the field of soundscape design for outdoor performance venues. Future research could investigate the effectiveness of different tree species and planting configurations for noise absorption within amphitheaters. Additionally, studies

exploring the psychological impact of various natural soundscapes on audience enjoyment and well-being during performances would provide valuable insights.

4. Conclusion

In conclusion, the soundscape is the element that must be considered in planning an outdoor amphitheater as it suits the function and topology of the building and space. Based on this analysis, spatial arrangements for outdoor amphitheatres are the performance space to be enclosed while the sides can be opened to refract the sound from dispersing and becoming unwanted sound to excess space. If the performance space has no backdrop, planting monotonous and massive trees helps to attenuate sound from refracting to the back. The gradient with a slight gradient of 2% - 5%, is generally being kept below 5% to avoid obstruction to accessing each seating and to maintain the reverberation time for the outdoor amphitheater, the seating material shall be coefficient with absorption properties materials such as wood and bamboo. These are the ideal materials for outdoor amphitheater seating. By strategically arranging the vegetation, it is possible to drastically increase the noise attenuation for an outdoor soundscape. With the characteristics of Dipterocarp tree species such as size (they are gigantic trees with abundant resin), voracious leaves (simple, entire, stipulate, stipules small sometimes surrounding the internode), legume trees (seed or bean-like fruit), big strangler fig bushes, scaly or fissured bark, and the toots are tap, branched and deep are the characteristic that assists in attenuate sound. Human comfort in acoustic experience is co-related with a visual experience that conveys the diverse perspectives and emotions in their experience in an outdoor setting. In the context of designing an outdoor amphitheater, the element of making the ambiance merge with the natural sound produces a maximum experience in both acoustic and visual. This study acknowledges certain limitations. The case study focused on a single rainforest amphitheater, limiting the generalizability of the findings to other rainforest settings with potentially different vegetation compositions and acoustic characteristics. Additionally, the study relied on short-term sound pressure level measurements, which may not capture the full dynamic range of the soundscape throughout the year or across different weather conditions. Future research with a broader scope and long-term data collection can address these limitations and strengthen the generalizability of the findings. Building on this study's foundation, future research should expand case studies to encompass a wider range of rainforest amphitheater settings. Delving deeper into the sound absorption properties of specific tree species and implementing long-term soundscape monitoring would further refine design strategies. Additionally, investigating the psychological impact of natural soundscapes on audience experience and utilizing computational modelling to optimize designs before construction are promising avenues for future exploration. These efforts will enhance our understanding of soundscape design in rainforest amphitheaters and promote the creation of sustainable, audience-cantered performance spaces that harmonize with the rainforest environment.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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