# The effect of geometric variable design configuration on the acoustic quality of the auditorium (systematic literature review)

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**Abstract.** Poor acoustics may impede communication and user experience, and yet traditional design approaches often ignore the varying acoustic needs. The present paper systematically reviews pertinent literature to assess how flexible geometric design options (e.g., adjustable surfaces, modular panels, or dynamic surfaces) affect relevant acoustic parameters (reverberation time, clarity, and sound distribution) in comparison with conventional empty auditorium designs. By following PRISMA Protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) applied strictly to ensure transparency and reproducibility of the research process, 25 experimental and simulation studies from Scopus, Science Direct, Journal of The Acoustical Society of America, Sage, MDPI, and others were analyzed. Results indicate that proper geometric design can improve acoustics quality variation, particularly in multipurpose applications; however, implementation must consider cost and technical complexity. Therefore, conclusions and recommendations serve as an evidence-based guideline for architects and acoustical engineers involved in designing adaptive performance spaces in terms of real-time adjustment technologies and smart materials. On the other hand, new standards for acoustic evaluation of dynamic designs should also be created.

## 1 Introduction

Acoustics of performance spaces is one of the most important elements in auditorium design, and the functional success of a building often depends on it. Good acoustic quality not only improves sound intelligibility and listening comfort, but also enhances interaction between performers and audiences and increases the utility and aesthetic value of the space. Known as key design parameters, geometric elements such as the basic shape of the space, total volume, and interior surface configuration are among the factors that influence acoustic quality. They directly affect the reflection, diffraction, and propagation characteristics of sound waves [1]. Although advances in computer-based acoustic simulation have made early design evaluation easier, there is still the problem of combining acoustic principles with architectural decisions in a holistic and understandable way. Therefore, a thorough understanding of how

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geometric variables affect acoustic performance is essential to help designers reach ideal solutions from the conceptual stage [2].

Many modern performance buildings still face acoustic problems such as uneven sound distribution, non-ideal reverberation time, and acoustic anomalies such as local echoes or sound focus. However, the role of geometric design in auditorium acoustics has long been recognized. Inaccurate consideration of the influence of room shape, volume, and surface configuration during the early design stage often leads to discrepancies between acoustic expectations and actual results. In addition, it is still difficult for architects and acoustic consultants to make evidence-based design decisions because the complex relationship between geometric parameters and the acoustic response of the room is not fully understood quantitatively and systematically. As the population grows, the need for an analytical framework that can link the choice of shape and material with acoustic performance indicators is increasing. Demands for flexible yet quality multi-purpose space performance.

The purpose of this article is to provide a comprehensive review of the literature that has been written on how geometric parameters—specifically room shape, total volume, and interior surface configuration—influence the acoustic performance of auditoriums. This study aims to find effective design patterns, evaluate the acoustic evaluation techniques used, and map the relationship between geometric choices and key acoustic parameters such as reverberation time, clarity, speech intelligibility, and distribution of sound. By conducting a critical analysis of previous studies. The expected outcome is a reference framework that can assist architects, acoustic engineers, and performance building planners in the design decision-making process at an early stage of the process.

Many studies have looked at how geometric design affects the acoustics of performance spaces. However, there is a lack of comprehensive understanding of the relationships between form, volume, and surface configuration in the context of high-performance acoustic parameters. Previous studies have been fragmentary, concentrating on one or two geometric variables in isolation, and using inconsistent methods and performance indicators. Furthermore, few studies have presented a systematic synthesis of the various design approaches that have been tested through empirical case studies, physical models, and computational simulations. In order to form an accessible knowledge base that can be used to guide evidence-based design, these findings need to be integrated. Therefore, this systematic review aims to fill this gap by providing a structured and comprehensive analysis of the existing literature.

By using a systematic and comprehensive approach in studying the impact of geometric variables on the acoustic performance of auditoriums, this study offers a new contribution. These geometric variables are often viewed partially in previous studies. This study differs from conventional literature reviews that tend to be descriptive because it combines results from various disciplines, such as audio technology, building physics, architecture, and civil engineering. It also classifies design patterns based on their acoustic effectiveness. This study also critically evaluates various acoustic analysis techniques found in the literature. Thus, it can provide methodological suggestions for future research. It is hoped that the results will not only improve the theoretical understanding of the relationship between form and sound but also offer practical guidelines to help designers make more informed and evidence-based initial design decisions.

## 2 Methodology

To identify, evaluate, and synthesize the available knowledge on the influence of geometric parameters on the acoustic performance of auditoriums, this study uses a systematic literature review (SLR) approach. The SLR approach was chosen because of its ability to provide an objective, transparent, and replicable summary of the existing literature, as well as to help

find effective design patterns in the context of acoustic references.

Using a combination of keywords such as “geometry design for auditorium acoustics quality", “variable design for auditorium acoustics quality" and "auditorium architectural acoustic optimization", were used to conduct a comprehensive literature search through various leading scientific databases such as Google Scholar 200 literatures and Scopus 257, concentrating on case studies or simulations of performance space acoustics, and examining relevant geometric variables were the inclusion criteria. However, publications that did not meet these criteria were excluded if they did not include quantitative acoustic analysis, abstracts that were not fully accessible, or publications that were not relevant to the main topic.

After the initial selection stage, which was based on the title and abstract, the articles that met the criteria were thoroughly screened through content analysis, the PRISMA flow chart can be seen in figure 2. Information on the auditorium shape, room volume, surface configuration, and acoustic evaluation techniques were included in the extracted data. It also included key acoustic parameters such as reverberation time (RT), speech intelligibility (STI), clarity (C80), early decay time (EDT), and sound distribution. In addition, the articles were categorized based on the type of study used (empirical, computer simulation, physical model), type of space (concert, theatre, multi-purpose hall), and design strategies used.

Synthesis analysis is done by identifying trends and patterns of relationships between geometric elements and acoustic responses. The results are summarized in the form of categorization tables and conceptual diagrams to facilitate interpretation by readers and architectural design practitioners.

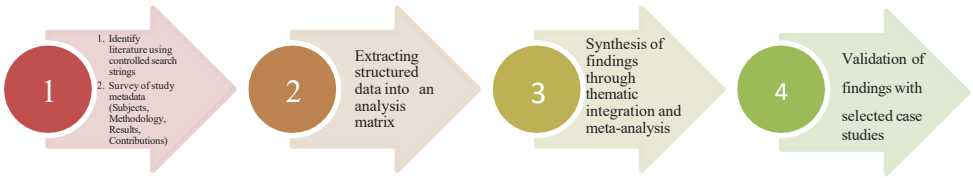


**Fig. 1.** General flow chart diagram of methodology.

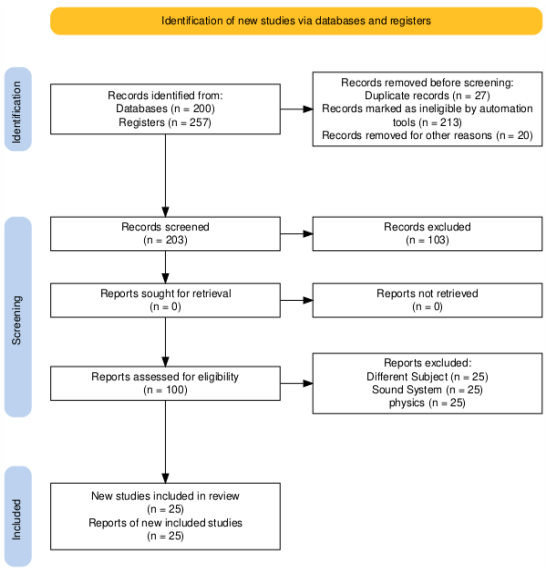


**Fig. 2.** Flowchart of PRISMA diagram [3].

## 3 Results and discussion

In determining the acoustic quality of an auditorium, it is necessary to explore the indicators that influence the acoustic quality, by quoting from Hochgraf, 2019 who cited an example of an acoustic indicator wheel for a concert hall auditorium from Kuusinen and Lokki, 2017, the wheel can be seen in figure 3 below.

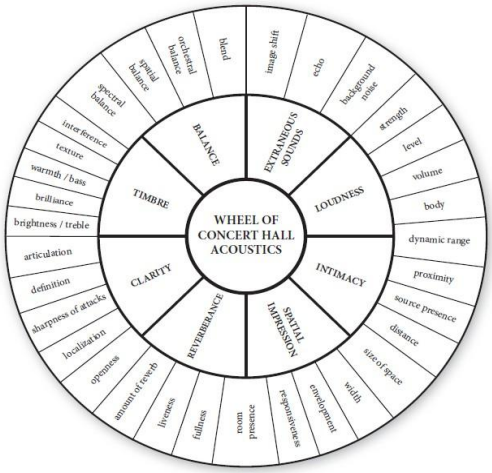


**Fig. 3.** Wheel of concert hall acoustics [4].

As seen in the acoustic wheel above, the relevant perceptual factors are grouped into eight categories: clarity, reverberation, spatial impression, intimacy, loudness, balance, timbre, and minimization of extraneous noise.

### 3.1 Journal extraction

In this section, the topics of 20 scientific journal article metadata from various sources are extracted and arranged into a table by identifying research subjects, methodology, results and contributions. Which are presented in table 1 below.

**Tabel 1**. Arrangement of Scientific Journal Articles based on research subjects, methodology, results and contributions.

| No. | Title | Journal | Subject | Methodology | Result | Contribution |
|---|---|---|---|---|---|---|
| 1 | Objective and subjective evaluations of twenty-three opera houses in Europe, Japan, and the Americas [5] | Journal of the Acoustical Society of America -1 Jan 2000 | Identified key factors influencing acoustic quality, including reverberation time, intelligibility and spaciousness of 23 Opera houses. | - Stretched impulse response measurement.<br>- A questionnaire is sent to the conductor for acoustic rating. | -The relationship between objective parameters and subjective ratings is analyzed.<br>-The opera house which is not horseshoe-shaped, can be rated the best opera house with its shape. | - Collect acoustic data for 23 opera houses.<br>-Conductor survey acoustic ratings of 23 opera houses. |

| No. | Title | Journal | Subject | Methodology | Result | Contribution |
|---|---|---|---|---|---|---|
| 2 | Effect of Geometry on Sound field atria [6] | Building Simulation 2017 | Investigating the effects of geometry on sound pressure level and reverberation time. | -Parametric study of the effects of atrium geometry. -Computer simulation using the ODEON Room Acoustics Program. | -Length and height reduce the average sound pressure level (SPL). -T 30 varies with skylight shape and slope. | -Analyze acoustic comfort and speech intelligibility in the atrium. |
| 3 | Impact of Curve Surfaces In Performance Spaces [7] | NMNH Division of Mammals 05 Oct 2022 | Investigating the influence of curved surfaces on the acoustics of gallery spaces, cathedrals and halls. | -Experimental methods for acoustic evaluation. -Computer simulation for performance analysis with ODEON. | -Curved surfaces have minimal negative acoustic impact. -Evaluation using experimental methods and computer simulations. | The impact of curved surfaces on galleries, churches and halls |
| 4 | Architectural shape and early acoustic efficiency in concert halls (L) [8] | The Journal of the Acoustical Society of America 2012 | Investigation of basic geometric relationships on acoustic energy efficiency. | -Predict initial energy using solid angles. -The formula shows the factors that affect the average initial energy. | -Early reflections from shallow angles increase acoustic efficiency. -Geometry significantly affects the average early reflection energy in a concert hall. | -Correlation between reflector area and C80 clarity. -Efficient reflectors increase the strength of early reflections. |
| 5 | Auditorium Acoustics and Architectural Design [1] | International Journal for Multidiciplinary Research 2023 | -Selection of materials for auditorium acoustics | -Basic guidelines and methods for auditorium acoustic planning. -The importance of an integrated approach to auditorium design | NRC values of materials that affect the acoustic quality of the auditorium | An integrated approach to auditorium design that considers acoustics and experience for the audience |
| 6 | Auralization: Fundamentals of Acoustics, Modelling, Simulation, Algorithms, and Acoustic Virtual Reality [9] | The Journal of the Acoustical Society of America 2008 | Acoustic auralization | Acoustics with computer simulation with a numerical approach. | Presenting acoustic simulation with rendering simulation | Facilitates acoustic value analysis with signals and reproduces them with a computer. |

| No. | Title | Journal | Subject | Methodology | Result | Contribution |
|---|---|---|---|---|---|---|
| 7 | Coherent image source modeling of sound fields in long spaces with a sound-absorbing ceiling [10] | MDPI Applied Sciences 2021 | Sound prediction in Long room (Underground traffic corridor) | Coherent sound image modeling by numerical methods | Numerical modeling of coherent sound images is more accurate for predicting sound | With the sound coherent image method, it is possible to predict the sound in the underground tunnel. |
| 8 | FDTD Simulation Study of Acoustic Enclosure Shape [11] | Euronoise 2021 | Initial prediction of the influence of shape on the acoustic quality of a room | FDTD (Finite Different Time Domain) simulation method | The concave shape resultsin poor sound distribution. | Provides initial information in designing forms that affect the acoustic quality of a room. |
| 9 | The influence of concert hall architecture on acoustics (the effect of musical performance) [12] | E3S Web of Conferences 2023 | Examines the influence of architecture on concert halls, such as shape, dimensions, materials, seating and stage positions and sound equipment. | Analyzing 4 concert halls in the world | The shape, dimensions, materials, seating and stage positions and good sound equipment will make the acoustic quality good. | Provides information on the importance of architectural elements to the acoustic quality of a concert hall. |
| 10 | Analysis of the impact of architectural variables on 1 acoustic perception in concert halls 2 [13] | Journal of Environtmental Psychology 2016 | Examining the impact of architectural variables on the acoustic perception of concert halls.(19 concert halls) | Differential semantic methods and asking about the perceptions of architects and non-architects. | Acoustic perception is influenced by visual components and acoustic parameters. | Assessing concert hall acoustics from architectural variables and the perceptions of an architect and a non-architect |
| 11 | The Art of Concert Hall Acoustics: Current Trends and Questions in Research and Design [14] | acousticstoday.org | Researching trends, concert hall designs and research questions | Literature review on factors that influence acoustic quality and its parameters | Auralization will never be able to replace the real experience of listening to music in a concert hall, but it can help innovate in perfect acoustic design.. | Provides information on acoustics and influencing factors, as well as auditorium acoustic design methods. |

| No. | Title | Journal | Subject | Methodology | Result | Contribution |
|---|---|---|---|---|---|---|
| 12 | Harmonizing Spaces: Investigating the Intersection of Sound and Architectural Design [15] | Stidues in Art and Architecture 2024_pioneer | Investigation of the relationship between sound and building design | -Interdisciplinary collaborative approach<br>-User-centered approach | This study revealed that poor acoustics can significantly impact a variety of outcomes, such as learning effectiveness in educational settings, patient recovery in healthcare facilities, employee productivity in the workplace, and overall well-being in urban areas, highlighting the importance of acoustic design in these environments.. | This study contributes to the field of architectural acoustics by providing insight into the critical role of sound in building design, emphasizing the need for a balance between technical acoustic performance metrics and subjective perceptual qualities such as ambiance and emotional resonance. This understanding assists architects and designers in creating environments that enhance the human experience. |
| 13 | The Acoustical Design of Concert Halls [16] | Sage Journals_Building Acoustics 1994 | Study and analyze some concert halls in the world | Explaining the principles of acoustic attributes in concert halls | Concert hall acoustic design criteria | Providing acoustic design guidelines for concert halls |
| 14 | Active acoustics in concert halls - A new approach [17] | rchives of Acoustics (2011) | Active acoustic analysis | Active acoustic approach with Virtual acoustic technology | The use of active acoustics helps the performance of acoustic quality. | Active acoustics are very helpful as a practical solution |
| 15 | Perceptual studie in Concert Hall Acoustics [18] | Doctoral Desesrtasi | Acoustic perception in concert halls at live concerts | -audience questionnaire<br>-acousticauricles with | -found differences in acoustic quality in the initial sound and reflected sound in several concert halls.<br>-wood panel affects the clarity of the balance between direct sound and reflected sound | Contribute to the use of appropriate methods in analyzing the acoustic quality of concert halls. |

| No. | Title | Journal | Subject | Methodology | Result | Contribution |
|---|---|---|---|---|---|---|
| 16 | A comparison of three diffuse reflection modeling methods used in room acoustics computer models [19] | The Journal of the Acoustical Society of America 1996 | Comparing sound propagation and reflection with 3 methods | -simulation of sound absorption and reflection with computers, models and real conditions | There is a match between measurements in the field and simulations carried out, both with computers and large-scale models. | Contributing 3 accurate simulation methods for measuring sound reflection and propagation. |
| 17 | Deep, data-driven modeling of room acoustics: literature review and research perspectives [20] | Forum acuticum Euronoise 2025 | Literature review Acoustics with Deep Learning method | Conceptual comparison of traditional physical data models with Deep Learning methods | Deep Learning methods are more powerful and faster than traditional physical data models. | Contribute to research and design in the field of acoustics, which can provide information quickly and accurately. |
| 18 | Comparative analysis of machine learning algorithms on prediction of the sound absorption coefficient for reconfigurable acoustic meta-absorbers [21] | ScienceDirect_Elsevier 2023 | Comparison of absorption coefficient predictions | Analysis method with machine learning algorithm for acoustic material absorption coefficient | Artificial neural network (ANN), k-Nearest Neighbor (kNN), and radial basis function neural network (RBFN) methods, the results are more accurate with ANN. | Contribution of a more accurate beta-absorption configuration measurement method in acoustic materials. |
| 19 | Data Driven Room Acoustics Modelling [22] | Doctoral Thesis | Researching low-cost acoustic design and measurement methods | Data modeling methods with machine learning | Neural network computer applications provide efficient and low-cost acoustic analysis and design. | Contribute to reducing research costs in the field of acoustics |
| 20 | Using Machine Learning to Predict Indoor Acoustic Indicators of Multi-Functional Activity Centers [23] | MDPI Applied Science 2021 | Examining the acoustic quality of a multi-function auditorium. | Machine learning ANN and GBDT as acoustic indicator prediction tools in multi-function auditoriums | Evaluation and prediction of acoustic indicators becomes simpler, faster and more accurate without using 3D-Modelling simulation software. | Contribution to acoustic indicator analysis becomes simpler, faster and more accurate. |
| 21 | Directional assessment of acoustic stage support in a drama theatre [24] | Acoustics 2008 | The effects of using a multidimensional microphone | Microphone setup on stage with simple equipment | The microphone setup provides good acoustic potential on stage. | Make it easy for stage actors to hear each other |

| No. | Title | Journal | Subject | Methodology | Result | Contribution |
|---|---|---|---|---|---|---|
| 22 | improving the acoustic performance using sustainable materials case study: lecture rooms [25] | FUJE | Evaluating the acoustic quality of the auditorium space | Digital acoustic simulation with CATT | The acoustics in both classroom auditoriums are less than optimal. | Replacing acoustic materials on old interior elements with sustainable materials |
| 23 | Acoustics and Sustainability: A Built Environment Perspective [26] | International Journal of Acoustics and Vibration 2020 | Editorial on the influence of good acoustics on the built environment | Literature study on the relationship between acoustic comfort and sustainable built environment development | Acoustics must be essential to sustainability | Acoustics can be integrated into various standards and regulations on sustainability. |
| 24 | sustainable acoustics: the impact of ai on acoustics design and noise management [27] | Technical Science 2024 | The Impact of AI on Acoustics and Noise Control | Exploring the role of AI in acoustics in this era | With the collaboration of AI with acoustics, sounds from various environments can be created optimally. | AI can contribute to the creation of optimal acoustics |
| 25 | BIM-based framework for indoor acoustic conditioning in early stages of design [28] | Sociedad Española de Acústica 2019 | This paper primarily focuses on developing a framework and tools for early stage acoustic conditioning in building design, utilizing Building Information Modeling (BIM) methodology | This paper outlines a development-oriented methodology: first, conceptualizing a BIM-based framework, and then, implementing software tools within that framework to address specific acoustic design challenges | The main outcome of this research is the proposal of a framework that integrates Building Information Modeling (BIM) methodology for decision making during the early design stages. | The main contribution of this paper revolves around the integration of acoustic considerations into the early stages of building design through the use of Building Information Modeling (BIM). |

## 3.2 Discussion

### *3.2.1 Interpretation of results*

From the Literatures extraction above, we get, that A systematic analysis of the literature shows a significant correlation between geometric parameters of auditoriums and their acoustic performance. In terms of shape, rooms with trapezoidal, splayed walls, or horseshoe configurations tend to provide more even sound distribution than square or rectangular shapes that often produce acoustic anomalies such as sound focus or local echoes. Room volume has also been shown to have a direct effect on reverberation time, with larger volumes requiring more intensive absorption strategies to maintain sound intelligibility, especially in concert halls and theaters. Interior surface configurations—such as the use of diffusers, textured panels, or strategic reflective elements—have been shown to play an important role in improving clarity and speech intelligibility, especially in multi-purpose auditoriums. These findings are in line with the basic principles of building acoustics that state that the interaction

between shape, materials, and volume determines the propagation pattern of sound waves in an enclosed space.

### *3.2.2 Impact on theory and practice*

From a theoretical perspective, the results of this study enrich the understanding of the dynamics of the form-acoustic relationship, which has previously only been studied partially in the literature. This study successfully identified design patterns that can be used as references in predicting acoustic responses based on initial geometric choices. In practice, these findings provide evidence-based design guidance for architects and acoustic engineers in the early design decision-making process. For example, the use of asymmetrical shapes and diffusive surfaces can be recommended to avoid sound distortion in large halls. In addition, these results are relevant for architectural education, as they can be the basis for a more integrative curriculum between aesthetic aspects and technical performance in the design of performance spaces.

### *3.2.3 Research limitations*

As a systematic review, this study has several limitations that should be noted. First, the variety of acoustic evaluation methods in the literature—ranging from computer simulations to field tests—leads to data inconsistencies that make in-depth quantitative analysis difficult. Second, most of the reviewed studies focus on specific geographic and cultural contexts, so generalizations of the findings should be made with caution. Third, some studies did not include empirical validation or presented only qualitative results, so the interpretation of causality between geometric design and acoustic performance remains inferential. Therefore, the results presented should be viewed as an initial analytical framework, not a final conclusion.

### *3.2.4 Suggestions for future research*

To overcome these limitations, further research is strongly recommended to develop more precise predictive models through the integration of AI-based acoustic simulations and physical experiments. A hybrid approach between quantitative and qualitative methods will help to validate the geometry-acoustic relationship more objectively. In addition, comparative studies across cultures and auditorium types—such as traditional concert halls versus modern multi-purpose halls—can provide more inclusive insights into the different acoustic needs. The development of machine learning-based design tools or digital twin technology is also a promising area to support real-time decision-making in future auditorium planning.

### *3.2.5 Social implication and etic*

From a social perspective, the results of this study emphasize the need for inclusive acoustic design, especially for people with hearing impairments or other vulnerable groups. Good acoustics are not just about sound quality, but also about equal accessibility of information and cultural experiences. On the ethical side, the use of digital technology in acoustic simulations raises issues of transparency and accountability in design decision-making. The algorithms used must be independently evaluated to avoid bias or unvalidated assumptions. Furthermore, multidisciplinary collaboration between architects, engineers, acousticians, and

social scientists is essential to ensure that technological innovations remain in favor of humans and the environment.

# 4 Conclusion and suggestions

## 4.1 Conclusion

This study shows that the geometric design of an auditorium—including the shape of the room, the total volume, and the configuration of interior surfaces—has a significant influence on its acoustic performance. A systematic analysis of the available literature reveals design patterns that are effective in improving key acoustic parameters such as reverberation time, clarity, speech intelligibility, and sound distribution. Trapezoidal shapes, splayed walls, and the use of diffusive elements on interior surfaces tend to provide better acoustic results than symmetrical or flat designs. In addition, the volume of the room must be carefully considered to avoid excessive reverberation time or poor speech intelligibility. These findings demonstrate that a holistic understanding of the interactions between geometric elements is essential in the initial planning process of an auditorium.

## 4.2 Suggestions for practitioners and researchers

For architectural practitioners and acoustic engineers, these findings recommend an evidence-based design approach that integrates acoustic principles from the early stages of design. The use of digital acoustic simulations, combined with empirical case studies, can be an effective tool in evaluating alternative designs. For future researchers, it is highly recommended to develop predictive models based on machine learning or digital twin technology to improve the accuracy of acoustic analysis during the conceptual phase. Further cross-cultural and multidisciplinary studies are also needed to expand the knowledge base on the need for more inclusive and adaptive acoustics.

## 4.3 Policy and education implications

In the context of architecture and acoustic engineering education, the results of this study suggest the need for the integration of building acoustics topics into the design studio curriculum. In addition, government institutions and professional organizations are encouraged to formulate national or international design guidelines that include evidence-based recommendations regarding geometric optimization in auditoriums. Thus, this study not only contributes to the development of architectural acoustic theory, but also has real potential to improve the quality of public performance spaces in the future.

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