The Acoustics of Open-Air Theatres: Why Traditional Parameters Don't Apply

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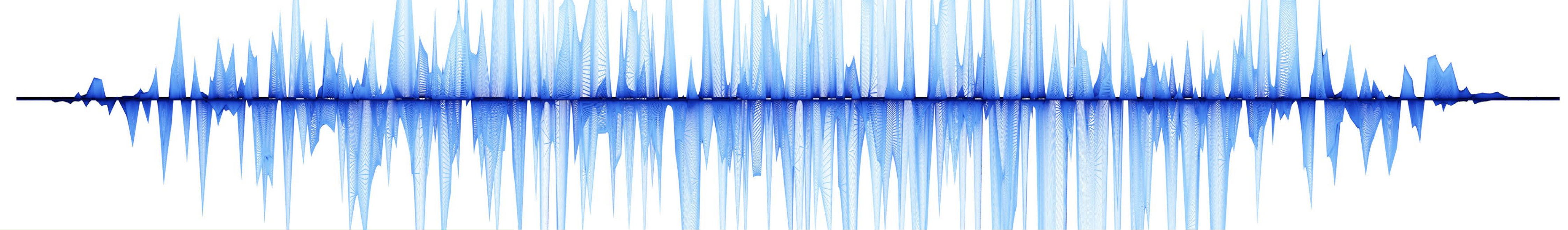


The Acoustics of Open-Air Theatres: Why Traditional Parameters Don't Apply

When you sit in an ancient Greek theatre, marvelling at how clearly you can hear performers even in the back rows without microphones, you're experiencing acoustic engineering that predates modern science by millennia. According to new research, many of the standard methods acousticians use for concert halls are ineffective for open-air venues. Dr Jens Holger Rindel of Odeon A/S in Denmark has demonstrated why we need different acoustical parameters to evaluate open-air theatres properly. His work challenges the conventional wisdom of applying indoor concert hall metrics to outdoor venues and proposes new approaches specifically tailored to spaces where the sky forms the ceiling.

Why Open-Air Theatres Need Their Own Acoustic Measures

Since the development of modern acoustics, engineers have relied on a standard set of parameters to evaluate performance spaces, primarily focusing on reverberation time – the measure of how long sound persists after the source has stopped. This approach works well for enclosed venues like concert halls, but Dr Jens Holger Rindel's research reveals why it is fundamentally unsuitable for open-air theatres.

In an enclosed space, sound reflects off walls and ceilings multiple times, creating a dense pattern of reflections that smoothly decay over time. In contrast, open-air theatres have sparse reflections primarily from the *orchestra* floor, stage elements, and seat rows. In an ancient theatre, the circular surface between the scene building and the audience is called the *orchestra*. Without a ceiling to trap sound, most energy escapes upward, resulting in very different acoustic conditions.

This fundamental difference means that many standard measurements produce unreliable or meaningless results when applied to open-air venues. Dr Rindel demonstrated this by conducting detailed computer simulations of the ancient Greek theatre at Epidaurus, widely regarded as one of the acoustic wonders of the ancient world.

The Problem with Reverberation Time in Open Spaces

Dr Rindel's analysis begins by examining the impulse responses – 'acoustic fingerprints' – of the Epidaurus theatre with reconstructed scene building and a full audience. Four different source positions were applied. The results immediately reveal why traditional parameters fail. It is characteristic that there are very few early reflections, resulting in a noticeable gap between the direct sound and sound reflections. This gap creates highly irregular decay patterns, making standard reverberation measurements unreliable.

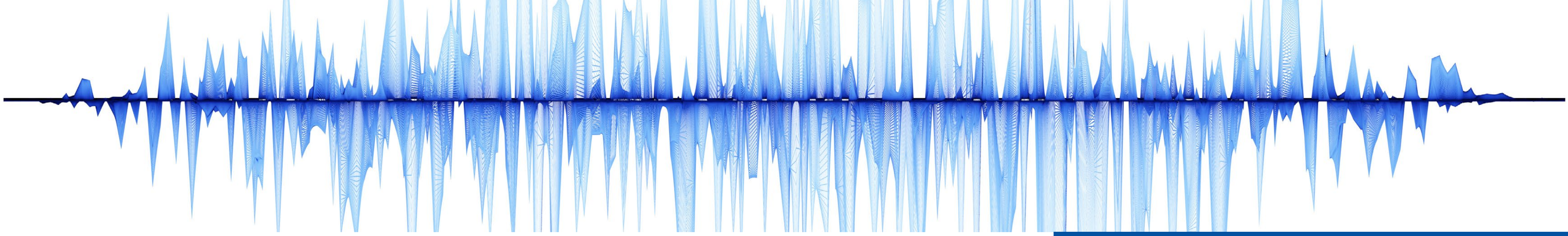
Early Decay Time (EDT), which measures how quickly the initial 10 decibels of sound energy decay, proved particularly problematic. In the Epidaurus simulations, EDT values varied wildly depending on source position – from 3.34 seconds to just 0.14 seconds – with extremely high variability that rendered the measurements essentially meaningless.

Similarly, the standard reverberation time (T_{20}) exhibited significant spatial variation and failed statistical quality tests, indicating whether the measurement should be considered reliable. After thorough analysis, Dr Rindel concluded that neither EDT nor T_{20} are meaningful parameters for an open-air theatre.

What Really Matters in Open-Air Theatre Acoustics

If conventional reverberation parameters don't work, what should acousticians use instead? Dr Rindel identifies three critical aspects of open-air theatre acoustics that need different approaches to measurement: sound strength (loudness), speech clarity, and echo detection.

For sound strength, the parameter *G* (measured in decibels) remains useful. This measures how much louder the sound is in the theatre compared to the same source in an open field at a 10-metre distance. In Dr Rindel's simulations, the *G* values across different positions in the Epidaurus theatre showed a strong correlation with the overall loudness of speech from a performing actor.



Dr Rindel also proposes a new parameter called 'acoustical efficiency' (*E*), defined as the amplification of the sound provided by the theatre, or the difference between the total sound level and the direct sound alone. This provides a more comprehensive measure of how effectively a theatre design facilitates sound propagation from various source positions.

For speech clarity, the parameter D_{50} (definition) proved the most reliable. This measures the ratio of sound energy arriving within the first 50 milliseconds to the total sound energy. Higher values indicate better speech clarity. The simulations showed excellent clarity in positions where actors would traditionally perform in the Epidaurus theatre.

Importantly, Dr Rindel demonstrates why the commonly used Speech Transmission Index (STI) can be misleading in open-air theatres, as it does not adequately account for the more serious problem of echoes in outdoor settings.

The Echo Problem in Open-Air Acoustics

One of the most significant insights from Dr Rindel's research is the importance of properly detecting and measuring echoes in open-air venues. Unlike enclosed spaces where late reflections blend into a smooth reverberation, distinct late reflections in open-air theatres can create noticeable and distracting echoes.

Echo problems are more likely to occur in an outdoor environment where the reflection density is much lower than in a room. For this purpose, Dr Rindel recommends using the Dietsch echo parameter, which evaluates whether specific reflections arriving after 50 milliseconds are likely to be perceived as distinct, disturbing echoes.

The simulations revealed potential echo problems with certain source positions in the Epidaurus theatre, particularly when performers stood at the front of the *orchestra*. This finding has important implications for understanding how ancient theatres were used. Actors would have known intuitively to avoid positions that created echo problems, even without the scientific tools to measure them.

Practical Applications for Ancient Theatre Reconstruction

To demonstrate the practical value of these alternative parameters, Dr Rindel conducted simulations using a speech source with characteristics similar to those of a loud human voice, such as an ancient Greek actor might have produced. The results showed A-weighted sound pressure levels between 51 and 55 decibels across the theatre – remarkably close to the ideal range for speech comprehension.

However, the simulations also revealed that source position significantly affected both loudness and potential echo problems. Positions near the back of the *orchestra* or on the *proscenium* (raised stage) proved acoustically superior to positions at the front of the *orchestra*. These findings align with historical accounts. The Roman architect Vitruvius noted in his treatise *De Architectura* that the acoustics of theatres are highly dependent on the source position, a fact also well-known in antiquity.

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By demonstrating the limitations of traditional parameters and proposing alternatives specifically suited to outdoor venues, the study offers valuable insights for understanding both ancient and modern open-air performance spaces.

Credit: Jens Holger Rindel

Recommendations for Evaluating Open-Air Theatres

Based on his findings, Dr Rindel recommends a new approach to evaluating open-air theatre acoustics, focusing on three key parameters: Sound Strength (G), Definition (D_{50}), and the Echo Criterion using the Dietsch parameter.

Dr Rindel also proposes his new acoustical efficiency parameter as a global measure for comparing different theatres or different stage configurations within a theatre. Unlike sound strength, which varies significantly with distance from the source, efficiency remains relatively constant across the audience area, making it useful for overall acoustic quality comparisons.

Implications for Modern Venues and Future Research

While the research focuses primarily on ancient Greek theatres, the findings have significant relevance for modern outdoor performance spaces. Many contemporary amphitheatres and outdoor venues suffer from poor acoustics because they're designed using principles better suited to enclosed spaces. By applying Dr Rindel's alternative parameters during the design phase, architects could create more effective open-air venues that achieve good speech clarity and adequate loudness without relying on electronic amplification.

The proposed acoustical efficiency parameter, while promising, requires further validation through physical measurements in existing ancient theatres and modern open-air venues. The influence of weather conditions – particularly wind, temperature gradients, and humidity – on open-air acoustics also merits further investigation.

A New Framework for Open-Air Acoustics

Dr Rindel's research presents a compelling case for reevaluating the acoustics of open-air theatres. By demonstrating the limitations of traditional parameters and proposing alternatives specifically suited to outdoor venues, the study offers valuable insights for understanding both ancient and modern open-air performance spaces.

The findings highlight the remarkable acoustic engineering achieved by ancient Greek theatre designers, who created venues with excellent speech clarity and sufficient loudness without the benefit of modern acoustic science. By using more appropriate measurement techniques, we can better appreciate and learn from these ancient acoustic achievements.

For contemporary acousticians, architects, and preservationists, the research provides practical guidance for evaluating, designing, and restoring open-air venues. Rather than imposing inappropriate indoor standards on outdoor spaces, Dr Rindel's alternative parameters offer a more nuanced and accurate way to understand the unique acoustic properties of theatres where the sky forms the ceiling.

This new framework not only enriches our understanding of ancient acoustic knowledge but also provides valuable tools for creating modern outdoor venues that can achieve the seemingly magical acoustic qualities that have captivated audiences in places like Epidaurus for over two millennia.

MEET THE RESEARCHER

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Dr Jens Holger Rindel earned his MSc (1971) and PhD in Acoustics (1977) from the Technical University of Denmark. With over 50 years of experience in architectural acoustics, he served as a professor at the Technical University of Denmark until 2007 and is the founder and senior researcher at Odeon A/S, developing room acoustics software. Dr Rindel has led masterclasses worldwide and delivered more than ten keynote speeches at international conferences. He is a Fellow of both the Institute of Acoustics and the Acoustical Society of America, and an Honorary Member of the acoustical societies of Denmark and Norway. He has published textbooks on building, architectural, and environmental acoustics. Dr Rindel has also held significant leadership roles, including president of the Nordic Acoustic Association and convenor of ISO working groups. He has led EU-funded research projects on musical acoustics and the acoustics of ancient buildings, worship spaces, and Roman theatres.

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FURTHER READING

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