



HAL
open science

The Past Has Ears at Notre-Dame - Research and public outreach using virtual reconstructions

Brian F. G. Katz

► **To cite this version:**

Brian F. G. Katz. The Past Has Ears at Notre-Dame - Research and public outreach using virtual reconstructions. Proceedings of the 2026 Spring Meeting of the Acoustical Society of Japan, Acoustical Society of Japan, Mar 2026, Tokyo, Japan. pp.415-418. <hal-05566882>

HAL Id: hal-05566882

<https://hal.science/hal-05566882v1>

Submitted on 25 Mar 2026

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY 4.0 - Attribution - International License

The Past Has Ears at Notre-Dame

- Research and public outreach using virtual reconstructions

○ Brian Katz [ブライアン・カッツ] (CNRS, Sorbonne University)

1 Introduction

The 2019 fire at Notre-Dame de Paris triggered renewed scientific interest in the cathedral's acoustics. The aim is to understand how sound behaves in this space, how it evolved over time, and how it supports musical practice. This work is part of the project “The Past Has Ears at Notre-Dame” (PHEND) [1]. Within PHEND, we developed a digital acoustic twin of the cathedral, allowing simulation and auralization of different historical states, linking architectural and archival evidence to measurable room-acoustic parameters. While PHEND was primarily a research project, it also emphasized dissemination. Several immersive audio productions were created using the same models, enabling non-specialists to experience key results directly.

2 Overview of Research Efforts

At its core, the work presented here relies on geometrical acoustic numerical simulations of the acoustics of the Cathédrale Notre-Dame de Paris that aim to reconstruct, as faithfully as possible, the acoustic behaviour of the cathedral and to understand how this behaviour results from its geometry and materials. The resulting acoustic model serves as the foundation for investigating the cathedral's acoustics across multiple historical periods.

The modelling effort was initially based on a detailed representation of the modern architectural state of the cathedral, corresponding to its condition prior to the 2019 fire (circa 2015). This reference model was calibrated by pre-fire acoustic measurements of the same period. Subsequent measurements during the reconstruction enabled a direct comparison between pre-fire and post-fire conditions, highlighting significant changes in reverberation time and related room-acoustic parameters, providing quantitative insight into the acoustic evolution of the cathedral following the fire [2].

Beyond global acoustic indicators, complementary studies examined the role of specific Gothic ar-

chitectural elements in shaping the sound field. In particular, numerical and experimental scale model investigations addressed the contribution of columns to sound scattering within the cathedral. These studies showed that such elements play a measurable role in the perceived acoustic environment, especially in a space of this scale [3].

The digital model was subsequently adapted to represent different historical periods using available architectural, iconographic, and written documentation (*e.g.* [4]). These historically informed reconstructions made it possible to address a range of research questions related to acoustic heritage, such as studies on medieval organ placement in the cathedral [5]. A second example concerns the acoustic impact of large devotional paintings, known as the *Mays*, which were displayed in the nave during specific periods. Their presence as both absorbing and reflecting obstacles was investigated for various historical installation configurations [6].

A defining feature of PHEND was the explicit integration of human perception and musical practice into the interpretation of acoustic reconstructions. Rather than treating acoustics as a purely physical phenomenon, the project considered sound as part of a lived cultural experience. An interdisciplinary study combining acoustics and anthropology examined the auditory memory of Notre-Dame prior to the 2019 fire. This work highlighted how musicians, clergy, and regular users of the space perceived and adapted to its acoustics, emphasizing the role of lived experience in intangible cultural heritage [7].

PHEND investigated historical preaching practices through acoustic analysis [8]. This line of work focused on physically based modelling approaches rather than perceptual auralisation, in order to examine sound propagation, speech intelligibility, and source-receiver relationships under historically plausible conditions. In parallel, virtual acoustic environments were used as experimental tools to study how musicians adapt their performance to different states of the cathedral's acoustic and for different

「ノートルダム大聖堂の〈過去〉は耳を持つ—仮想再構築を用いた研究と社会発信」

historical repertoires [9], framing sound as a culturally embedded practice rather than a purely technical constraint.

Finally, PHEND developed immersive and interactive dissemination tools, including a real-time 6DoF audio panning plug-in [10] and virtual reality experiences, enabling researchers, heritage professionals, and the public to explore historically reconstructed soundscapes. In all, the project established a reference framework for the scientific study, preservation, and transmission of acoustic heritage.

3 Public Outreach Efforts

The PHEND project placed strong emphasis on public outreach and on the dissemination of research results beyond the academic community. An explicit objective was to make acoustic heritage accessible, intelligible, and experientially meaningful to a broad audience. These efforts targeted cultural institutions, heritage professionals, the media, and the general public, while maintaining scientific rigour and methodological transparency [11]. Figure 1 presents several images from these public-facing productions.

A major component of PHEND’s outreach strategy consisted of immersive reconstructions of historical sound environments disseminated through publicly accessible digital platforms. These formats rendered the acoustic heritage of Notre-Dame de Paris accessible to non-specialist audiences. Users were able to explore historically informed soundscapes of the cathedral across multiple periods, transforming complex acoustic simulation data into perceptually intuitive experiences suitable for cultural mediation, education, and exhibition contexts.

Among the earliest public-facing works was *Ghost Orchestra*¹, a virtual concert extract reconstruction highlighting how the cathedral’s acoustics vary with listening position [12]. Initially presented as an interactive installation, it was later converted into a YouTube360 video, taking advantage of the platform’s 3D audio support. Although originally created in 2015, its graphical rendering was updated in 2020 within the framework of the PHEND project.

The web-radio style project *La Vierge 2020*² presents the full-length reconstructed concert used in *Ghost Orchestra*, but as an audio-only produc-

¹<https://www.dalembert.upmc.fr/lalam/Projets/index.php?page=GhostOrchestra>

²<http://lavierge2020.pasthasears.eu/>

tion [13]. Produced during the extended COVID-19 lockdown in Paris, it allows listeners to choose among several predefined listening positions, using pre-rendered binaural audio.

*Looking for Notre-Dame*³ presents a four-part radio fiction constructed around Victor Hugo facing writer’s block [14, 15]. A mysterious muse appears and he travels through time, experiencing the acoustic history of Notre-Dame. Each scene taking place within the cathedral employs auralisations, while key elements of PHEND’s research are woven into the narrative. Supplemental information is made available on the accompanying website for listeners seeking additional detail.

Expanding this narrative and experiential approach, *Notre-Dame Whispers*⁴ is an Android and iOS audio-guide presenting the audible and acoustic history of the cathedral, with options for on-site geo-localised use or off-site listening [15, 16, 17]. Released during the reconstruction phase, it allows users to walk around the exterior of the building while listening to the interior acoustic history. Additional materials, including extended interviews, are also provided.

*Vaulted Harmonies (ArchéoConcert)*⁵ is a film exploring the relationship between the evolution of Notre-Dame’s Gothic architecture and its musical history. This is achieved by coupling simulated acoustics with eleven musical works associated with the cathedral, each newly recorded performance rendered in historically relevant acoustic conditions and presented as a virtual concert [18]. With a rich accompanying website, current actions are for shortened 360° planetarium and immersive VR versions.

A particularly visible collaboration within PHEND’s outreach activities was the interactive multimedia feature “A Cathedral of Sound”, published by *The New York Times Magazine*⁶. This production integrated spatial audio directly into a web-based journalistic narrative, allowing readers to experience reconstructed sound fields while engaging with historical and scientific context. PHEND contributed the visual 3D model, spatial audio renderings, and technical guidance, playing a central role in the credibility and impact of the

³<http://lookingfornotredame.pasthasears.eu/>

⁴<http://ndwhispers.pasthasears.eu/>

⁵<http://vaultedharmonies.pasthasears.eu/>

⁶<https://www.nytimes.com/interactive/2023/03/03/magazine/notre-dame-cathedral-acoustics-sound.html>

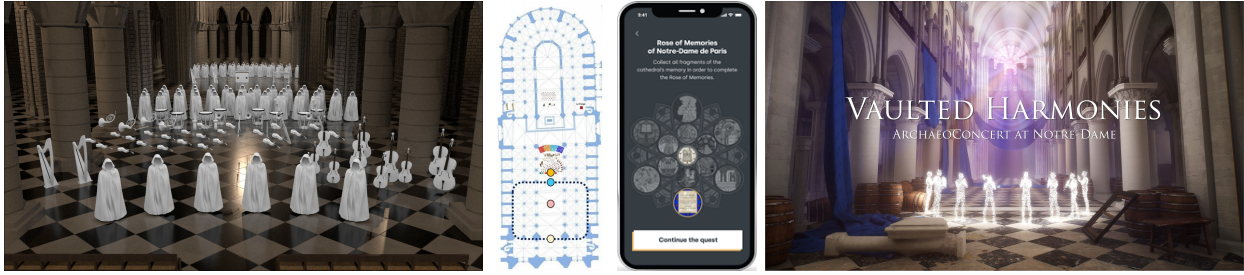


Fig. 1 Graphics from different productions, from left-to-right: Ghost Orchestra, La Vierge 2020, Notre-Dame Whispers, Vaulted Harmonies.

feature. The production received wide international attention and was recognised as a finalist for awards in *Excellence in Immersive and Emerging Technology Storytelling* and *World's Best Digital News Design* (2023), noted as a landmark example of immersive storytelling in mainstream media.

Through these combined efforts, PHEND translated advanced research in archaeoacoustics into accessible and engaging public-facing formats. These productions increased public awareness of intangible acoustic heritage and established reference models for disseminating sound-based cultural research beyond academic audiences.

4 Public Reception of Productions

The public reception of these productions was characterised by sustained national and international visibility. This response reflects strong interest in the acoustic dimension of cultural heritage, as well as in the innovative methods developed to make this dimension accessible to non-specialist audiences. The project's outputs reached well beyond academic communities, engaging the general public through major media outlets, cultural institutions, and widely used digital platforms.

One indicator of this reception was the extensive media coverage following the 2019 fire. Research results and expert commentary associated with PHEND were featured in newspapers, radio broadcasts, television programmes, and podcasts across France, Europe, North America, and Japan [19]. This coverage positioned the project as a key scientific reference for explaining how the fire affected the cathedral's sound environment⁷, and for highlighting why acoustics represent an essential, yet often overlooked, component of built heritage. The frequency of these interventions and their wide

geographical distribution point to a sustained public demand for scientifically grounded perspectives on acoustic heritage. To provide an indication of the reach of these outreach activities, a summary of user engagements associated with these productions is presented in Table 1⁸.

Taken together, the reception of the PHEND productions demonstrates that acoustically informed reconstructions are able to engage broad audiences when presented through accessible and immersive formats. The project's ability to attract media attention, institutional interest, and public engagement confirms the relevance of acoustic heritage within contemporary cultural discourse and supports the value of integrating acoustics into heritage communication strategies.

Acknowledgements

First and foremost, sincere acknowledgements to all those who have contributed to the research and production products, including researchers, writers, actors, musicians, production engineers, and more. Principal funding has been provided by the European Union's Joint Programming Initiative on Cultural Heritage project PHE (The Past Has Ears, Grant No. 20-JPIC-0002-FS, phe.pasthasears.eu), the French project PHEND (The Past Has Ears at Notre-Dame, Grant No. ANR-20-CE38-0014, phend.pasthasears.eu), and the *Chantier scientifique CNRS/Ministère de la Culture/Notre-Dame*. Additional financial support for productions was provided by Audible R&D, the *Collegium Musicae* and *Observatoire des patrimoines de l'Alliance Sorbonne Université*, and the *DIM Patrimoines matériels – innovation, expérimentation, résilience* (PAMIR). Special thanks to Cathédrale Notre-Dame de Paris personnel for assistance and patience during measurements. Access for researchers to the

⁷ 「無形のものを復元する（音響遺産）」ノートルダム大聖堂と首里城—2019年の火災を越えて (<https://www.notredame-shurijo.com/html/readmore-notredame05-rm04/#1>)

⁸ Comparable access data were not available for the New York Times Magazine interactive feature.

Table 1 Access data up to end of 2025 for various public outreach productions. For *Notre-Dame Whispers*, the reported 1 h duration does not include the additional resources in the form of extended interviews.

Production Title	Year	Description	Duration	Downloads, etc.
Ghost Orchestra	2015 (2020)	YouTube360, virtual concert extract	≈5 min	≈ 80k views, totalling 1628 hours or ≈ 20k full views
La Vierge 2020	2020	Web, radio virtual concert	≈1 h	≈ 5.7k visits, 891 active listeners
Looking for Notre-Dame	2023	Audible, radio-fiction	≈1 h	Listening started ≈ 6.2k times, totalling 3135 hours
Notre-Dame Whispers	2024	Mobile application, audio-guide	≈1 h	≈ 2.7k downloads
Vaulted Harmonies	2025	YouTube, virtual concert	≈1 h	≈ 2.1k views, totalling 203 hours (ignoring public events)

cathedral’s restoration worksite has been made possible thanks to the public administrative establishment responsible for the conservation and restoration of Notre-Dame de Paris.

References

- [1] Mullins, *et al.* “The Past Has Ears at Notre-Dame Cathedral: An Interdisciplinary Project in Digital Archaeoacoustics”. In: *Acoustics Today* 20.2 (2024). (URL), pp. 49–58.
- [2] Katz, *et al.* “An acoustic survey of the Cathédrale Notre-Dame de Paris before and after the fire of 2019”. In: *Acoustics* 2.4 (2020). SI: Historical Acoustics, pp. 791–802. DOI: [10.3390/acoustics2040044](https://doi.org/10.3390/acoustics2040044).
- [3] Weber, *et al.* “Sound scattering by the Gothic piers and columns of the Cathédrale Notre-Dame de Paris”. In: *Acoustics* 4 (2022). SI: Acoustics, Soundscapes and Sounds as Intangible Heritage, pp. 679–703. DOI: [10.3390/acoustics4030041](https://doi.org/10.3390/acoustics4030041).
- [4] Borne, *et al.* “The Interior Restoration of Notre-Dame de Paris (1845–1869): A Historical Study for an Architectural and Acoustic Reconstruction”. In: *Heritage* 8.12 (2025). Joint Heritage/Acoustics SI: The Past Has Ears: Archaeoacoustics and Acoustic Heritage. DOI: [10.3390/heritage8120525](https://doi.org/10.3390/heritage8120525).
- [5] d’Alessandro, *et al.* “The position of Gothic organs in Notre-Dame de Paris: architectural evidence, acoustic simulations, and musical consequences”. In: *Applied Acoustics* 231 (2025). SI: Selected papers on Room Acoustics at Forum Acusticum 2023, 110506:1–10. DOI: [10.1016/j.apacoust.2024.110506](https://doi.org/10.1016/j.apacoust.2024.110506).
- [6] Canfield-Dafilou, *et al.* “Can you hear the paintings? The effect of votive offerings on the acoustics of Notre-Dame”. In: *Forum Acusticum*. Turin, Sept. 2023, pp. 2537–2544. DOI: [10.61782/fa.2023.0841](https://doi.org/10.61782/fa.2023.0841).
- [7] De Muynke, *et al.* “Ears of the Past, an inquiry into the sonic memory of the acoustics of Notre-Dame before the fire of 2019”. In: *J Cultural Heritage* 65 (2022). SI: Notre-Dame, pp. 169–176. DOI: [10.1016/j.culher.2022.09.006](https://doi.org/10.1016/j.culher.2022.09.006).
- [8] Canfield-Dafilou, *et al.* “History and Acoustics of Preaching in Notre-Dame de Paris”. In: *Heritage* 7.12 (2024). Joint Heritage/Acoustics SI: The Past Has Ears: Archaeoacoustics and Acoustic Heritage, pp. 6614–6628. DOI: [10.3390/heritage7120306](https://doi.org/10.3390/heritage7120306).
- [9] Mullins. “Des voix du passé : the historical acoustics of Notre-Dame de Paris and choral polyphony”. Ph.D. Thesis. Sorbonne Université, Sept. 2024. <https://theses.hal.science/tel-04879114>.
- [10] Poirier-Quinot, *et al.* “RoomZ: Spatial panning plugin for dynamic RIR convolution auralisations”. In: *AES Intl Conf Spatial and Immersive Audio*. (URL). Aug. 23, 2023, 19:1–7.
- [11] De Muynke. “Reconstructing acoustic heritage : Methods and tools for interdisciplinary research and audio-augmented experiences”. Ph.D. Thesis. Sorbonne Université, Apr. 2025. <https://theses.hal.science/tel-05319073>.
- [12] Postma, *et al.* “Virtual reality performance auralization in a calibrated model of Notre-Dame Cathedral”. In: *Euroregio*. (URL). Porto, June 2016, 6:1–10.
- [13] Katz, *et al.* “La Vierge 2020 : Reconstructing a Virtual Concert Performance Through Historic Auralisation of Notre-Dame Cathedral”. In: *Intl Conf 3D Audio (I3DA)*. 2021, pp. 1–6. DOI: [10.1109/I3DA48870.2021.9610849](https://doi.org/10.1109/I3DA48870.2021.9610849).
- [14] Katz, *et al.* “The Past Has Ears at Notre-Dame: Immersive audio experiences for public engagement”. In: *Audio Eng Soc Conv 156*. (URL). Madrid, 2024, 251:1–8.
- [15] Katz, *et al.* “The Past Has Ears at Notre-Dame: Acoustic digital twins for research and narration”. In: *Digital Applications in Archaeology and Cultural Heritage* 34 (2024). SI: Digital Heritage Twins from Artificial Intelligence to Storytelling, e00369:1–16. DOI: [10.1016/j.daach.2024.e00369](https://doi.org/10.1016/j.daach.2024.e00369).
- [16] Peichert, *et al.* “Notre-Dame Whispers : a geolocated immersive walk through the sonic memory of Notre-Dame de Paris Cathedral”. In: *Proc. Gothic Resonances*. 2024, pp. 105–128. DOI: [10.5281/zenodo.14163355](https://doi.org/10.5281/zenodo.14163355).
- [17] De Muynke, *et al.* “Public evaluation of notre-Dame Whispers, a geolocated outdoor audio-guided tour of Notre-Dame’s sonic history”. In: *Heritage* (2026). Joint Heritage/Acoustics SI: The Past Has Ears: Archaeoacoustics and Acoustic Heritage (in press), pp. 1–23.
- [18] Poirier-Quinot, *et al.* “Vaulted Harmonies: Archaeoacoustic concert in Notre-Dame de Paris”. In: *Acoustics* 7.4 (2025). Joint Heritage/Acoustics SI: The Past Has Ears: Archaeoacoustics and Acoustic Heritage, 66:1–20. DOI: [10.3390/acoustics7040066](https://doi.org/10.3390/acoustics7040066).
- [19] 井出. “魂を取り戻す音——再びよみがえる荘厳な響き 音響専門家たちの挑戦”. In: *共同通信* (Nov. 2023). (URL).