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Lucia Maria ORLANDI

Design graphique

Adeline GOYET

Design graphique, mise en page et illustration de couverture

Fabien TESSIER

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Avec le soutien de l'ANR pour le projet PHEND (The Past Has Ears at Notre-Dame) et
de l'European Union's Joint Programming Initiative on Cultural Heritage pour PHE (The Past Has Ears)

Notre-Dame Whispers

a geolocated immersive walk through
the sonic memory of Notre-Dame de Paris Cathedral

Stéphanie PEICHERT

Talkartive SAS, France
stephanie.peichert@talkartive.com

Julien DE MUYNKE

Institut Jean Le Rond d'Alembert, CNRS, Sorbonne Université, France
Eurecat, Technology Center of Catalonia, Multimedia Technologies, Spain
julien.de_muyne@dalembert.upmc.fr

Brian F.G. KATZ

Institut Jean Le Rond d'Alembert, CNRS, Sorbonne Université, France
brian.katz@sorbonne-universite.fr

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ABSTRACT

This work presents a novel audio-guided visit aiming to promote scientific research on the sonic identity of Notre-Dame de Paris Cathedral throughout its history, carried out in the context of the project PHEND (The Past Has Ears at Notre-Dame). Embedded in *Ekko of Notre-Dame de Paris*, a free mobile app available on Android and iOS with geolocation functionality, *Notre-Dame Whispers* invites French, English, and Spanish-speaking visitors to explore the sonic memory of Notre-Dame by strolling around the cathedral along a series of predefined GPS locations referred to as stops. At each stop, they get access to various audio pieces narrating a part of the cathedral's sonic history, comprising diverse topics such as its bells, the evolution of its acoustics throughout time, the soundscape of the medieval construction site and modern restoration site, early polyphonic chant, its organs, among others. Designed as a mediation tool intended for the general public, it stages in a playful and didactic manner some research results in acoustics, musicology, history, art history, architecture, and soundscape archaeology conducted by the PHEND research group. The main motivation of this work was to create an engaging visitor experience by presenting potentially complex research topics in a manner accessible to all, through lively storytelling and historically informed immersive soundscapes. *Notre-Dame Whispers* will be further used in an on-site scientific experiment to assess how personified narrative and spatial audio can help increase visitors' engagement and improve learning potential in the context of visiting a heritage site.



| | |
|---|------------|
| CONTEXT | 107 |
| NOTRE-DAME DE PARIS AND THE FIRE OF APRIL 2019 | 107 |
| THE PHEND PROJECT | 108 |
| NOTRE-DAME WHISPERS: A BRIDGE BETWEEN SCIENTIFIC RESEARCH AND THE GENERAL PUBLIC | 109 |
| DESIGN OF THE VISIT | 109 |
| PRELIMINARY STUDY | 109 |
| PROPOSED MEDIATION DESIGN | 116 |
| A MOBILE APP AS THE MEDIATION TOOL | 118 |
| PRODUCTION OF THE EXPERIENCE | 121 |
| IMMERSIVE STORYTELLING | 121 |
| NARRATOR'S VOICE RECORDINGS | 122 |
| AUDIO EDITING AND MIXING | 123 |
| EVALUATION | 124 |
| DATA ANALYTICS | 124 |
| IN SITU EXPERIMENT | 125 |

NOTRE-DAME WHISPERS

a geolocated immersive walk through the sonic memory
of Notre-Dame de Paris Cathedral

Stéphanie PEICHERT, Julien DE MUYNKE and Brian F.G. KATZ

CONTEXT

NOTRE-DAME DE PARIS AND THE FIRE OF APRIL 2019

Before the fire of April 2019, the cathedral was the most visited cultural site in France with about 12 million visitors a year.¹ At the time of writing, Notre-Dame de Paris is still undergoing post-fire restoration. Since then, the building has remained closed to the public, thereby diminishing dramatically the offer of on-site visits. The cathedral's reopening is planned to start progressively from December 2024. Nonetheless, thanks to its reputation and the interest generated by its fast-paced restoration, it still attracts many international visitors who mainly stay on the parvis to admire its façade.

If in the aftermath of the fire the immediate need to restore the iconic architecture of Notre-Dame became evident, it appeared simultaneously crucial to recover the intangible heritage represented by its acoustics. As part of the eight working groups from the Chantier Scientifique Notre-Dame de Paris² established by the French Ministry of Culture and National Centre for Scientific Research (CNRS) to assist teams working on the restoration of the cathedral, the group specialising in acoustics, coordinated by Brian F.G. Katz and Mylène Pardoën comprised researchers specialised in the field of sound, committed to documenting and understanding the sonic identity of the cathedral. Following the UNESCO resolution 39C/59 "The importance of sound in today's world: promoting best practices" (UNESCO, 2017) complementing the UNESCO Convention for the Safeguarding of the Intangible Cultural Heritage (UNESCO, 2018), these researchers undertook to delineate the research field on the sonic identity of Notre-Dame over the centuries. This involved tracing the evolution of the cathedral's acoustics, shaped by architectural and decorative modifications throughout history, along with exploring the semiotics of the soundscapes associated with it since its initial construction started in 1163.

1 <https://fr.statista.com/infographie/17718/nombre-de-visiteurs-de-sites-culturels-paris/> (accessed 31/01/2024).

2 <https://www.culture.gouv.fr/en/Thematic/Heritage-sciences/Research-themes/The-Notre-Dame-de-Paris-construction-site> (accessed 31/01/2024).

THE PHEND PROJECT

The research project PHEND (The Past Has Ears at Notre-Dame), funded by the National Research Agency (ANR) and a French extension of the European project PHE (The Past Has Ears), emerged concurrently with the Acoustics working group from the Chantier Scientifique Notre-Dame de Paris. It is an interdisciplinary project fostering collaboration between the humanities and social sciences with acoustics and digital sciences. Bringing together specialists of medieval musicology, virtual acoustic reconstruction applied to heritage spaces, liturgical history, art history, heritage architecture and soundscape archaeology, it aims at establishing digital historical models of Notre-Dame de Paris encompassing the geometric, visual, and acoustic dimensions of the building, and using these models to study and reconstruct historical soundscapes originating from the musical and sonic practice across the centuries. Digital models, rooted in architectural and archaeological archives and refined through collaboration with scientists involved in the restoration, serve as the cornerstone for the group's research. Focusing on pivotal moments in the cathedral's history with a particular emphasis on acoustics, they are used to explore the evolution of sociological, religious, and musicological practices at Notre-Dame through the lens of sound. For example, among various scientific questions, PHEND researchers assess the impact of the cathedral's acoustics on the musical performance of singing ensembles for various repertoires using virtual acoustic environments (Mullins and Katz, 2023). Other examples include an anthropological inquiry of the memory of the acoustics of Notre-Dame before the fire by the music practitioners (De Muynke, *et al.*, 2024), simulations of acoustic scenarios to evaluate the intelligibility of singing as a function of the singers' position and the presence or absence of the medieval *jubé*³ (Canfield-Dafilou, *et al.*, 2022a), recording and auralising the sounds of the past, e.g., the sound of the tools and materials used by the medieval builders (Pardoen and Guesney, 2023) or other sonic elements such as the bells and organs (Canfield-Dafilou, *et al.*, 2022b; d'Alessandro, 2024). Finally, PHEND researchers explore the possibilities offered by auralisation techniques for reproducing historical soundscapes combined with digital acoustic models of Notre-Dame Cathedral in an immersive and listener-centric manner. The culmination of these efforts results in historical sonic reconstructions, enabling a profound understanding of Notre-Dame's acoustic and sonic evolution by providing exceptional historically informed sound material that highlights this valuable intangible heritage.

3 The *jubé* was a large stone construction separating the choir from the nave on the west side that no longer exists. Remains of the *jubé* were recently discovered during the restoration of the floor pavement at the transept crossing.

NOTRE-DAME WHISPERS:

A BRIDGE BETWEEN SCIENTIFIC RESEARCH AND THE GENERAL PUBLIC

Notre-Dame Whispers was born at the end of 2022 out of the desire to make the PHEND and Acoustics working group research results available to the general public through a site-visit app developed by Talkartive.⁴ Following the earlier PHEND production podcast mini-series *À la Recherche de Notre-Dame*,⁵ highlighting the historical soundscapes of the cathedral through a fictional story set around Victor Hugo while he is writing his renowned novel, *Notre-Dame Whispers* is a research popularisation production that offers a visit into the sonic history of Notre-Dame de Paris. Primarily intended for on-site visitors, it takes them on a journey that spreads out around the cathedral, narrates the history of some of its key sonic components, and makes its historic soundscapes audible.

DESIGN OF THE VISIT

Prior to the production phase, an initial exploratory work phase took place, aiming to outline the contours of a visit route and develop its concept. This phase involved studying the topology of the cathedral's surroundings while it undergoes restoration, observing the types and habits of audiences present on-site, and undertaking documentation and classification of the research themes of the PHEND project while linking them to potential observation points distributed along the visit route. Subsequently, a collective reflection phase with the PHEND project group led to the proposal of an end-to-end comprehensive mediation solution to be deployed on-site.

PRELIMINARY STUDY

Walk around Notre-Dame's restoration site

The cathedral, closed to the public at the time of writing, is encircled by a temporary metal enclosure separating the restoration site from the public space. Nevertheless, its surroundings remain accessible to those who wish to observe it, especially if one decides to circumnavigate the monument, thereby enabling the design of a walk around the building as the visit route. The open parvis (i.e., the plaza in front of the cathedral), equipped with wooden tiered

4 <https://www.ekkoapp.art/> (accessed 31/01/2024).

5 <http://alarecherchedenotredame.pasthasears.eu/> (accessed 31/01/2024).

seating, provides tourists with a comfortable setting to observe the cathedral's façade (**Fig. 1**). From the parvis, it is easy to reach the Pont au Double and then the south bank of the Seine, walk along the monument's south side following Quai Montebello, cross the Pont de l'Archevêché to approach the chancel, get closer to the restoration base camp and its prefabricated modules by traversing Rue du Cloître Notre-Dame, and ultimately return to the parvis. As a complete stroll around the building seemed feasible, the visit route was designed along these stops. However, it must be noted that the extent of the restoration site is constantly evolving, leading to future restoration works potentially located along the visit route, e.g., on the parvis, thereby significantly impacting the visit route. Consequently, such changes of the restoration site extent must be anticipated in accordance with the rehabilitation plans established by the City of Paris, so that the visitor experience can be adjusted by proposing alternative routes through rapid updates of the mobile app.

Audience survey

Simultaneously to the site study, a series of observations were conducted regarding the influx of visitors around the monument and their behaviour. Results highlighted that Notre-Dame continues to attract several hundreds of visitors daily, interested in the progress of the restoration work and desiring to contemplate Notre-Dame de Paris from the outside. Many tourists, predominantly French, English, and Spanish speaking, as indicated by Paris tourism statistics on visitor's country of origin,⁶ come to the parvis every day, where they willingly linger for a while to admire the main façade of the cathedral. The public institution overseeing the restoration⁷ has installed mediation panels on the exterior of the restoration site's enclosure, informing passers-by about the damages provoked by the fire and the various actions taken as part of the cathedral's restoration (**Fig. 2**). This diverse audience, characterised by an international profile, mobility, and availability for a visit, is complemented by a less significant percentage of Parisians passing by the cathedral as part of their daily journeys, further contributing to this diversity. The high diversity of audience typologies motivated the creation of multilingual audio content and an adaption of the mediation tool to various levels of visitors' engagement as a function of their interest and the time they want to spend on-site. It then became evident that the proposed mediation tool must adopt a didactic approach and cater to a broad audience.

6 <https://pro.visitparisregion.com/chiffres-du-tourisme> (accessed 31/01/2024).

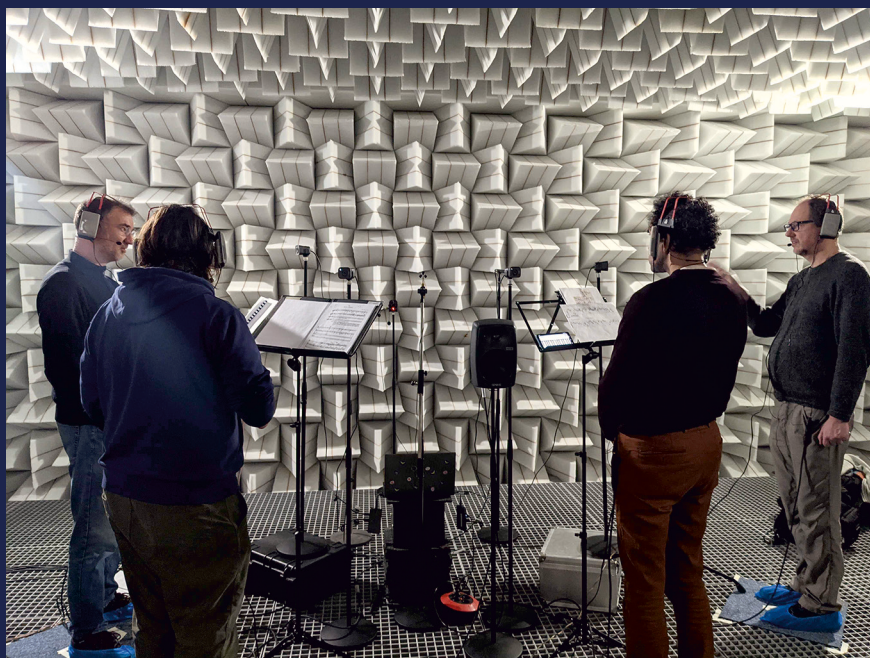
7 <https://rebatirnotredamedeparis.fr/en/l-etablissement-public> (accessed 31/01/2024).



Figure 1. View of Notre-Dame's main façade as seen from the tiered seating installed on the opposite side of the parvis (photograph by the authors, January 2024).



Figure 2. View of the mediation panels about the fire and the restoration work installed on the exterior of the restoration site's enclosure (photograph by the authors, January 2024).



a



b



c

Figure 3. a) Singing recording session in the anechoic room of Sorbonne University; b) Facsimile medieval organ recording with multiple proximity microphones; c) Bells recording from the belfry of Sens cathedral with a Neumann KU100 artificial head (photographs by members of the PHEND project).

Available audio corpus

The sonic material produced within the PHEND's research activities provides the foundations of the mediation tool. Regarding exterior soundscapes, the audio corpus primarily includes reconstructed historically informed soundscapes of Notre-Dame's construction and restoration sites from the Middle Ages, the 19th century and the 21st century. Notably, the sound of medieval tools was captured in Guédelon castle in northern Burgundy, a notable pioneering site employing the concept of Experimental Archaeology, whose construction is carried out using the technology and materials of the Middle Ages. As for the cathedral's interior, the material is diverse and abundant. These include several recordings of singing ensembles that were made during laboratory experiments involving virtual acoustic environments: early polyphonic chants performed in the reconstructed choir from late 12th century (**Fig. 3a**), and an antiphonal chant performed by a children choir and an adult choir in the cathedral from the early 15th century. Due to the unavailability of the cathedral's organs, the organ of Sainte Elisabeth de Hongrie Church in Paris and a facsimile of the medieval organ of Anaya Chapel in Salamanca's cathedral (**Fig. 3b**) were recorded using multiple proximity microphones, providing recordings intended to be further auralised in Notre-Dame's virtual acoustics from different periods in its history. Other interior sounds specific to church usage such as sermons, were recorded elsewhere and further auralised. Similarly, a recording session was organised in Sens cathedral (**Fig. 3c**) to capture audio material necessary for further reconstructing the sound of the bells of Notre-Dame from the 18th century, with which they share similarities in terms of chronology and manufacturing technique. During this recording session, various liturgical sounds were also recorded such as the creaking of the wooden stalls, the chancel grid opening, the burning of the incense and the thurible, footsteps in the bell tower, as well as RIRs in some church subspaces such as the belfry and the spiral staircase leading to the bell tower to be further used to auralise sound scenes in these subspaces. Finally, spatial recordings of various musical pieces performed in Notre-Dame before the fire of April 2019 by PHEND partner Conservatoire National Supérieure de la Musique et de Danse de Paris, sometimes involving large scale orchestra and choirs, such as the 2013 "Vierge de Massenet" concert (Katz, 2021), were also made available for auralisation purposes.

Choice of the observation points

It was desirable that the visit around the cathedral provides a multisensory experience involving visual and auditory dimensions, making necessary to identify specific stops along the visit route that allow visitors to approach the

cathedral using both senses. Therefore, the stop locations were chosen as they enable visitors to initially observe the cathedral and then engage in an auditory experience related to what they are observing (stop locations are shown in Fig. 4 and topics addressed in the associated audio pieces are summarized in Table 1). For example, the location of Stop 4 offers an unobstructed view on the cathedral's spire that collapsed during the fire of April 2019, as seen in Fig. 5, opening the way for the *Evening of April 15, 2019* audio piece narrating the sequence of events that led to that dramatic event. In addition to enriching the visitor experience, the view offered by these stops makes the presentation of the visit content more didactic, thereby enhancing learning potential.



Figure 4. Overhead map of the proposed visit route around Notre-Dame including the visitor's position (blue arrow) and the six stops (orange dashed square-boxes). List of stops: Parvis (1), Pont-au-Double (2), Quai Montebello (3), Quai Montebello (4), Pont de l'Archevêché (5), and Return to Parvis (6).

| | | |
|--------|---|--|
| Stop 1 | The queen of Gothic cathedrals | ND (the personification of Notre-Dame Cathedral) reminisces about the sounds of the Île de la Cité at the time of her first stone being laid. The island is buzzing with activity. She mentions the cathedrals that came before her and has V (the visitor) experience the difference of acoustics between those buildings and her own. |
| | A cathedral dedicated to the Virgin | ND explains that the cathedral is dedicated to the Virgin Mary and highlights the importance of Marian worship during the medieval times illustrated by various representations of the Virgin on and in the building. V is taken to the central nave to attend an orchestral performance of Jules Massenet's oratorio <i>La Vierge</i> , as it was recorded in the cathedral in 2013. |
| Stop 2 | Meeting with the bourdon Emmanuel | ND invites V to go up the south tower stairs heading for the renown tenor bell Emmanuel. After a short break on the Chimera gallery halfway up the tower, they reach the belfry, where V is introduced to Emmanuel and experiences the sound produced by its ringing in close-up. |
| | Each with its own name, each with its own sound | ND introduces to V all the bells from the two bell towers while they are ringing in full peal. Then, V listens to the sound of a bell cast, the pouring of bronze into the mould, and its polishing. Finally, V is taught the proper identity of each bell, through its name and note it produces. |
| Stop 3 | A ship of stone | After describing the general building structure, ND transports V to the opposite bank of the Seine, amid the medieval construction site (1170s). V follows the journey of a Parisian limestone block, from the dock to the facing wall of the cathedral, experiencing the sounds of stone cutting, mortar mixing, and the lifting onto a facing wall using a squirrel cage. |
| | A lost forest | ND guides V to the lodge of the carpenters, then transports V to 1240 in the cathedral's framework, called the forest and burnt during the fire of April 2019. V experiences the sound of this muted space and learns about the history and characteristics of this lost forest. |
| Stop 4 | Evening of April 15, 2019 | ND transports V back to the evening of April 15, 2019, to relive the fire that devastated the cathedral. They first attend the service from that day, and then move to the parvis to listen to the sound of the firefighters battling against the flames. Finally, they experience the sound of praying and singing by a group of onlookers gathered on the Archbishop's Bridge. |
| | The 21 st century construction site | ND transports V to the heart of the contemporary restoration site, first outside the cathedral's walls and then into the nave. V experiences the soundscape of the restoration site, perceiving the sounds of the craftsmen's activities, the restorers in action, the living area, and then follows the experts in acoustics during their measuring campaign. |
| Stop 5 | The School of Notre-Dame | ND transports V to the cathedral in 1199, during the Christmas celebrations. From the recently closed choir, V attends a performance of one of the first polyphonic chants produced in the cathedral. V listens to this iconic four-voice musical piece composed by Pérotin, <i>Viderunt Omnes</i> , performed by the singers positioned in front of the lectern, facing the main altar. |
| | Pueri chori | ND transports V to Palm Sunday of 1402, which marks the beginning of Easter week. V experiences the listening of the <i>Pueri Hebraeorum</i> , a chant organized in antiphony that combines children voices and adult voices. V learns more about this tradition of children singers and their daily lives while wandering along the nave towards the cathedral's main entrance. |
| Stop 6 | Stone monument / paper monument | ND transports V to the parvis of the 1830s to witness the multiple degradations that time and humans have inflicted upon the building. V learns about Victor Hugo's influence in bringing attention to its deteriorating state and the implementation of the restoration program by the architects Lassus and Viollet-le-Duc through their own interventions, which culminated in the cathedral's classification as a Historic Monument. |
| | The organs of Notre-Dame | ND transports V near the cathedral's Great Organ and teaches V the history of Notre-Dame's organs, explains how these instruments work, makes its wide variety of sounds audible, etc. V eventually aurally experiences from the nave a piece played on the Great Organ with four hands. |

Table 1. Title and short description of the audio pieces included in the visit.
ND stands for Notre-Dame and V for visitor.



Figure 5. View from Stop 4 of the cathedral's new spire, surrounded by scaffoldings, follow the collapse of the previous spire that burnt during the fire of April 2019 (photograph by the authors, January 2024).

PROPOSED MEDIATION DESIGN

A holistic approach

Based on the exploratory study's outcomes, the mediation production was designed following a holistic approach, aiming to adapt to visitation conditions and diversity of audiences, as well as to enhance the visit experience by proposing impactful content. It was then built upon three major components. Firstly, the concept of a free audio-guided tour accessible to all via a mobile app was developed as it provides a simple, mobile, and inclusive solution, thus democratising access to the visit. Secondly, the use of binaural audio content enabling for listener-centric spatial 3D sound scenes contributed to a significant level of immersion during the visit. Noteworthy, headphones are necessary for correctly reproducing binaural audio content and help visitors isolate themselves from the on-site background noise, further contributing to visitors' immersion in the spatial sound scenes and leading to a true exploratory auditory virtual reality experience. Thirdly, the strategic location of the stops around the monument enabled binding the tangible with the intangible, as they offer a view on the tangible parts of interest of the cathedral that serve as starting points for the auditory experiences highlighting the intangible cathedral's acoustic heritage.

Strategies fostering engagement of diverse audiences

Several strategies have been implemented to ensure that the visitor experience is well-adapted to a diversified audience. First and foremost, it was decided to produce the mediation tool in French, English, and Spanish to cover a broad audience. Moreover, the tour guide was chosen to be a fictional Notre-Dame, a very special narrator-character embodying the cathedral itself and speaking directly to the visitor, thereby contributing to intimacy. The audio content was complemented with iconographic and bibliographic resources for visitors interested in learning more about Notre-Dame's history and the associated scientific research. The visitors' engagement was also fostered by incorporating a gamification aspect into the visit with the concept of a quest, where they play an essential role in helping Notre-Dame retrieve her sonic memory. By listening to the audio pieces, each representing a particular memory of Notre-Dame, the visitors support her in the process of rediscovering her buried memories and are then encouraged to pursue their quest by listening to more audio pieces. To graphically mirror Notre-Dame's incomplete memory and the visitors' progress in the quest, inspiration was drawn from the cathedral's stained glass, particularly the medieval rose windows. A six-petal rose window aligned with the six stops was designed, including medallions symbolising the associated memories initially displayed as greyscale. The individual medallions illuminate with colours as visitors complete the listening of the corresponding memories. To successfully complete the quest, visitors are invited to explore all stops and associated audible memories, thereby contributing to the adornment of the rose window with vibrant colours.

A multi-modal experience

Following the approach promoted by the Special Interest Group on sensible mediation from the ICOM (International Committee for Education and Cultural Action)⁸ for designing mediation content in museums and described by Grassin (2022), *Notre-Dame Whispers* offers a multi-modal sensitive experience : the narrative presenting Notre-Dame's history engages visitors in both a sensory experience using their senses of hearing and sight, and an imaginary experience calling upon their imagination to self-picture the virtual audio scenes.

Being the common thread of the visit as she guides visitors through the entire experience, Notre-Dame alternately accompanies them in their own reality and in the various spacetimes they are transported to. Consequently, designed

8 <https://ceca.mini.icom.museum/new-special-interest-group-on-sensitive-mediation/> (accessed 31/01/2024).

audio pieces include alternating scenes falling under audio augmented reality experiences (AR) and audio virtual reality experiences (VR). For example, the introductory scene of each audio piece takes place in the present and in the cathedral's vicinity. These form the real-world setting onto which virtual audio elements are added, resulting in an audio AR experience. Subsequent scenes where the visitors are sonically transported to another spacetime to relive a memory of Notre-Dame are completely virtual, resulting in an audio VR experience.

A MOBILE APP AS THE MEDIATION TOOL

App development framework

As the visit offered by *Notre-Dame Whispers* is intended to function autonomously, the proposed mediation tool should not require any third-party hardware provided on-site (i.e., a traditional audio-guide). With the growing prevalence and computational power offered by smartphones equipped with stereo headphones, it was decided to have visitors use their personal mobile phones as the hardware device, as support of audio playback over headphones, geolocation functionality through GPS tracking, and a large touchscreen adequate for browsing multimedia content and displaying images and texts. Two different approaches were identified for the software development, namely a web-based solution where the content would be available through a web browser and a mobile app downloadable from the app stores. The mobile app approach was chosen as it has several advantages over the web-based approach:

- contrary to a web-based solution which requires a continuously working Internet connexion during the visit, a mobile app embeds all the necessary content and can be downloaded prior to the visit. Notably, visitors from countries outside the European Union may be subject to roaming charges when using an Internet connection;
- a mobile app offers a more controlled environment compared to a web-based solution, subject to web browser differences and associated dependencies, possible lacking certain necessary functionalities;
- an app allows for collection of user data through the app permissions system, enabling monitoring app usage and on-site most visited locations on a large-scale. These data, anonymously collected and covered by personal data protection law prohibiting their reuse or resale to third parties, provide metrics helping to improve the app, adjust the visit route, and detect potential bugs;
- users can be actively notified when a new app version is available through Push Notification system, for example when new audio content has been added.

Unity,⁹ a popular development platform primarily intended for video games, was chosen for the development of the mobile app *Ekko of Notre-Dame de Paris*,¹⁰ due to its high compatibility with multiple operating systems and platforms. Moreover, its native support of spatial audio may be an interesting asset for a future version of the app supporting head-tracked binaural audio reproduction. Firebase Analytics was included in the app for collecting user data in an anonymous way, providing key metrics such as the number of active users over time or the average app usage duration, and supporting the definition of custom events to be logged such as user locations along the visit route or the most listened to audio pieces.

UI/UX design

The UI was voluntarily made simple to avoid visual distraction, emphasizing the auditory experience. The UX was grounded on four main types of screens (Fig. 6), each dedicated to a key aspect of the visit: the map screen showing the visitor's position and the stops along the visit route, the audio player screen with standard playback controls, the playlist screen including a list of audio pieces available at each stop and associated iconographic and bibliographic resources, and the rose window screen showing the visitor's quest progress.

Initially, the visitors are guided to the first stop through the map screen. Once they reach the GPS zone delimiting the stop, their mobile phone vibrates, and a button appears indicating that the associated audio content is now available. A click on that button takes them to the audio player screen, where the first audio piece is automatically played back. On the audio player screen, the medallion corresponding to the currently played back audio piece is shown in place of the music album cover in a standard audio player. It is first displayed as greyscale as the associated memory has not been completed yet, and progressively turns coloured as the audio playback gets completed. When the audio playback is finished, the visitors are taken to the playlist screen, and the stop is considered as having been explored. From the playlist screen, they can choose to listen to another audio content that was just unlocked for the same stop, go back to the map screen to move on to the next stop, or look up at the image gallery and additional resources associated to the audio piece just completed. All multimedia content from an already explored stop is made

9 <https://unity.com/> (accessed 31/01/2024).

10 Ekko is a mobile app architecture designed to further embed other productions associated to other visit sites. *Ekko of Notre-Dame de Paris* is an ad-hoc version of Ekko specifically developed for the visit of Notre-Dame de Paris Cathedral via the content produced for *Notre-Dame Whispers*.

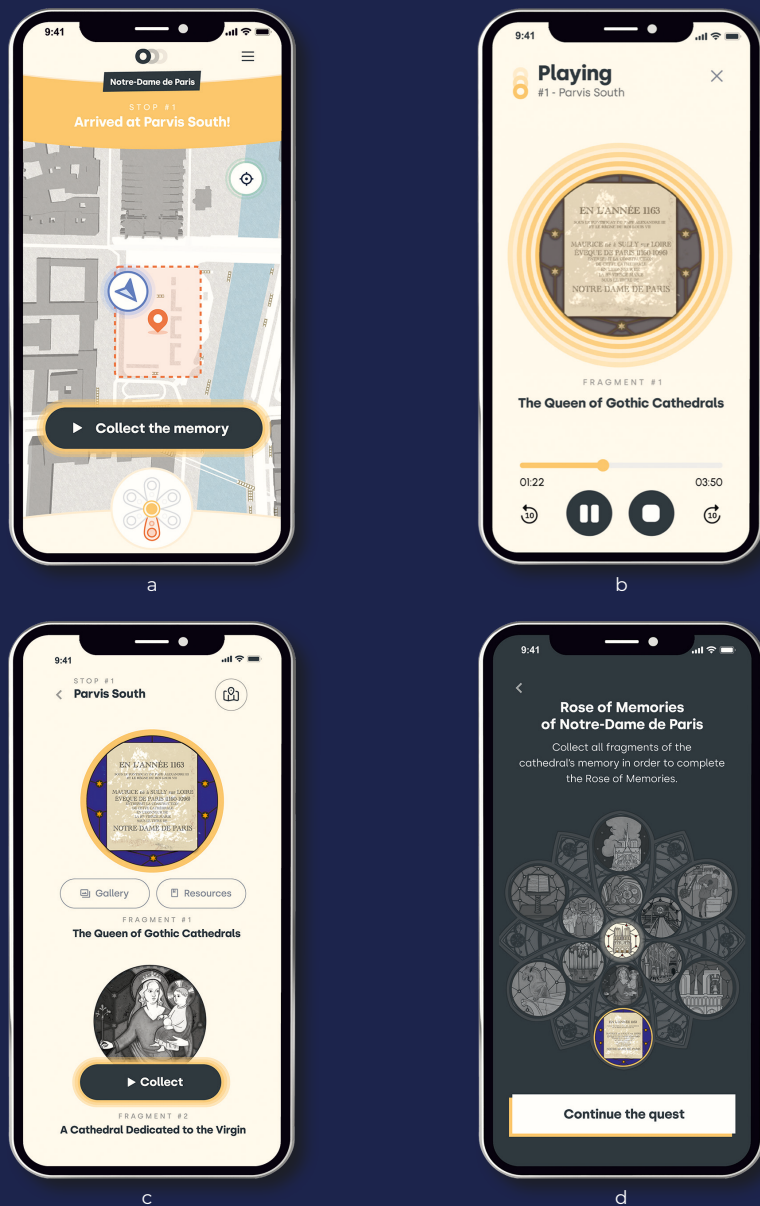


Figure 6. The four main screens of the mobile app *Ekko of Notre-Dame de Paris*. a) Map screen where the visitor has reached the GPS zone associated with Stop 1 activating the apparition of the button to access the corresponding audio content. The six-petal rose icon shown at the bottom leads to the rose window screen; b) Audio player screen of the first audio piece of Stop 1 displaying the associated medallion halfway between greyscale and coloured; c) Playlist screen including the two audio pieces of Stop 1. Shown here, only the first audio piece has been completed, giving access to the associated image gallery and additional resources; d) Rose window screen where only the first audio piece of Stop 1 has been completed.

available for good to visitors through manual exploration made possible from any remote location even after the visit. The rose window is always accessible via an icon located at the bottom of the map screen, enabling the visitors to check their quest progress indicated by the number of coloured medallions.

PRODUCTION OF THE EXPERIENCE

The production of the experience included the design of the storytelling, the narrator's voice recording, and the creation of the audio pieces to be embedded in the visit app.

IMMERSIVE STORYTELLING

A good story is often based on well-crafted and delineated characters, an incentive plotline encouraging the audience to go further, a series of twists and turns to achieve dynamism, and a subtle mix of poetry and explicitness in the narrative. This general rule was kept in mind during the production of the visit.

The narrator-character

To embody Notre-Dame Cathedral, it seemed appropriate to choose a timeless yet fragile narrator, to illustrate the physical state of the cathedral after the fire. The idea of a grandmother then became evident. In addition, she had to be an outstanding storyteller, a music lover, iconoclastic, both tender and lively, to foster visitors' engagement through empathy. The voice characteristic is equally crucial as it had to depict an elderly lady pleasant to listen to, maintain a certain level of comfort during the visit and facilitate immersion. Regarding the voice acting, the adequate narrator had to offer a large range of possible tones to cover the audio scenes diversity and demonstrate both educational skills and ability to create intimacy with the visitors, making herself seem like the grandmother of everyone while still embodying the cathedral itself.

The immersive script

The script was written from the outset considering the desired level of immersion. Like crafting a screenplay for a movie, the narratives were written concurrently with the audio creation process in an iterative way to maximise the level of realism of the virtual scenes as envisioned by the visitors. This led to the creation of audio piece mock-ups with a sketch voiceover helping craft

the script in the liveliest possible way. To achieve consistency along the visit, each audio piece was composed of a sequence of various phases as follows:

- observation phase: visitors observe the part of the building being described in the narrative;
- memory context phase: the part of the building being observed arouses a memory of Notre-Dame. Thereby, visitors are informed on the nature of the auditory experience they are about to live;
- memory experience phase: visitors are transported into a different spacetime illustrated by the historical soundscapes. Being surrounded by historically informed sounds spatialized in the corresponding virtual space and guided by Notre-Dame, they live the auditory experience from within.

In the observation phase, the narrative must guide the visitors' gaze towards the targeted part of the cathedral, e.g., the bell towers, the chancel, or the façade, sometimes requiring using terms from the religious architecture domain potentially unfamiliar to visitors. This pointed out the need to write the script in the most didactical possible way including explaining complex terms. In the Memory experience phase, the immersive character of the experience is achieved through the adequacy and synchronicity between the narrative and the spatialised soundscapes.

NARRATOR'S VOICE RECORDINGS

Studio sessions were organized to record the narrator's voice for each language version, under the supervision of a voice director who guided the narrator's voice acting. Prior to recording, the script of each audio piece was subdivided into smaller blocks of text to keep the voice takes within a reasonable time limit and displayed on a large wall screen to ease the reading for the narrator. Audio soundscapes corresponding to the individual text blocks were exported from the audio piece mock-ups without voiceover and used as audio playback over headphones during the narrator's voice recording sessions. This allowed the narrator to feel immersed in the described sound scenes, helping adapt her voice acting in tone and emotional state. For example, the narrative was almost whispered during the polyphonic singing performance in the medieval choir in *The School of Notre-Dame* audio piece (**Table 1**) to entail solemnity, was spoken with a voice louder than usual to compensate for the significant background work noise when walking on the scaffoldings of the modern restoration site in *The 21st century construction site* audio piece (**Table 1**), and quivered in *Evening of April 15, 2019* audio piece (**Table 1**), conveying anxiety as she recounted the struggle of the firemen to save the cathedral from the fire.

AUDIO EDITING AND MIXING

The editing of the audio content was done in Reaper digital audio workstation (DAW), as it natively supports multichannel audio of up to 128 channels per track.¹¹ This allowed use of Higher Order Ambisonics (HOA) recordings and pre-rendered scenes, as well as HOA room impulse responses (RIRs) through multichannel VST plugins for the room auralisation. HOA content was subsequently decoded in binaural using the Neumann KU100 artificial head non-individualized Head Related Transfer Functions (HRTFs).

Audio pieces comprise two main spatialised audio layers, namely the narrator's voice and the soundscapes, both processed with different spatialisation methods. Additionally, they were enriched with extra sounds from other categories, either issued from ad-hoc recordings or chosen from online audio libraries. These include ambience recordings, e.g., crowd on the parvis or audience in the nave, foleys spatially coinciding with either the narrator or third-party characters, e.g., narrator's steps during moving scenes, non-diegetic¹² sound effects, e.g., to symbolise travels in time, and background music in some intro and outro scenes.

The narrator's voice was binauralised, by processing the studio recordings through the dearVR Pro audio plugin, and augmented with room reverberation corresponding to the acoustic environment where the scene actually takes place. This conveyed a sense of head externalization, creating the illusion of a real character positioned within the listener's range, thereby yielding physical proximity and intimacy, while both were surrounded by the described scene. While most of the times the narrator stands in front of the listener, in some few scenes she stands on the listener's side as required by the scene setting, e.g., when they are seating side by side on the pews of the nave in *A cathedral dedicated to the Virgin* audio piece (**Table 1**), and sometimes slightly moves around the frontal position during moving scenes, e.g., when they are wandering together across the medieval construction site in *A ship of stone* audio piece (**Table 1**). Anaglyph audio plugin¹³ was also used to auralise a few nearby sources, such as the sound of the music book page flip in *The School of Notre-Dame* audio piece.

11 <https://www.reaper.fm/about.php> (accessed 31/01/2024).

12 Also known as “complementary sound”, a non-diegetic sound is any sound that does not originate from within the audio fiction's world, such as a sound effect or a music score. The term diegetic comes from the word diegesis, which is the evolution of a Greek term that means narration or narrative.

13 <http://anaglyph.dalembert.upmc.fr> (accessed 31/01/2024).

The soundscapes were composed out of various sound items of different nature. HOA pre-renders, as well as binaural, stereo, and mono recordings were mixed together to sonically match as much as possible the described scene as perceived from the listener position. Audio scenes of the medieval and modern construction sites were composed with a series of mono and stereo audio sources individually spatialised constituting composite ambience tracks, and pre-rendered in 3rd order HOA. These were further enriched with individual mono sources positioned near the listener, sometimes moving in space during moving scenes using plugin parameter automations, and directly rendered in binaural. For example, the medieval construction site soundscape used in *A ship of stone* audio piece (**Table 1**) was created with an ambience track including the sound of various workshops, machines, vehicles, crowds, animals, and the river flow, all rather distant from the listener, thus constituting a background audio layer further pre-rendered in 3rd order HOA. It was further enriched with the individual sounds of the tools, machines and worker actions fading in and out depending on the ongoing scene action, each positioned near the listener and in a direction consistent with the narrator's description of the ongoing scene. As opposed to the pre-rendered HOA ambience track, that cannot be compositionally altered, only rotated to simulate a change of perspective of the listener, spatialisation of individual sounds can be changed on request during the fine-tuning of the script parts where the narrator describes the ongoing scene.

EVALUATION

Several methods were considered for evaluating *Notre-Dame Whispers* and the associated mobile app *Ekko of Notre-Dame de Paris* as a mediation tool. These include analysing user data anonymously collected during the visit, as well as the results of a future in situ experiment aiming at assessing the visitors' satisfaction level for this novel type of visit and resulting learning potential.

DATA ANALYTICS

Upon agreeing with the Terms of Service of *Ekko of Notre-Dame de Paris*, the visitors accept that their location and their usage of the app during the visit will be stored and used by Talkartive for further analysis. Besides the basic key metrics such as the number of downloads or the number of active users, several custom events were created in Firebase Analytics allowing to monitor visitors' behaviour during the visit. These include the language used, the mobile type and operating system version, their location along the visit route, the time

spent at each stop, the list of explored stops, completed audio pieces, images and additional resources looked at, as well as the time spent on each app screen. Moreover, the app invites visitors to rate each audio piece on a five-star scale after playback is finished, providing feedback on which audio pieces they preferred. Similarly, after fully completing the quest through the six stops, they are encouraged to rate the app and write a review on the mobile app stores (App Store for iOS users and Play Store for Android users). All these data will be used for analysing visitor preferences regarding the multimedia content, the average visit duration, the clarity of the visit route and guiding, as well as for detecting potential bugs, for example if a significant number of visitors exit the app at the same stop or location.

IN SITU EXPERIMENT

A participative experiment shall be conducted on-site to assess the impact of spatial audio in the context of audio-guided visits of heritage sites. On-site participants will be provided with headphones and a mobile phone running various versions of the app *Ekko of Notre-Dame de Paris*, differing in their audio delivery format. After the visit, they will be asked to rate their satisfaction level following the methodology proposed in Bachiller, *et al.* (2023) and to answer questions helping to objectively evaluate the reception of the cultural experience and the learning potential offered by the different audio-guide versions, following the methodology proposed in Aristeidou, *et al.* (2023). These will include a downgraded version of *Ekko of Notre-Dame de Paris* with monaural audio delivery, following the example of standard handheld monaural audio-guides provided in many cultural visit sites, a static binaural delivery as offered by the general public version of *Ekko of Notre-Dame de Paris*, and the currently developed new version of *Ekko of Notre-Dame de Paris* with dynamic binaural delivery. The latter version will support connection over Bluetooth Low Energy to a lightweight head-tracker mounted on the headphones, embedding of Ambisonic audio content, and real-time binaural decoding as a function of the visitor's head orientation during the audio playback. Like a Virtual Reality experience displayed through a Head Mounted Display, the spatial sound scenes delivered by the dynamic binaural version will be anchored in the geocentric coordinates system rather than in the user-centric one, resulting in a potentially increased degree of realism of the reproduced sound scenes.



We have presented the novel audio-guided visit *Notre-Dame Whispers* promoting multidisciplinary research done by the PHEND project on the historical sonic identity of Notre-Dame de Paris Cathedral. Designed to adapt to a broad and diverse audience, this cultural and scientific mediation solution is embedded in the free mobile app *Ekko of Notre-Dame de Paris*, available for iOS and Android. It invites French, English, and Spanish-speaking visitors to an exploration of Notre-Dame's sonic memory through a geolocated stroll along a series of stops distributed around the cathedral, each offering a first-hand view on specific parts of the building. From these stops, the visitors' gaze is guided towards elements of the cathedral's architecture, forming the starting point of an immersive auditory experience narrated by a tender grandmother – a personification of Notre-Dame. She takes them to various spacetimes narrating some of her historical audible memories through lively storytelling enriched with historically informed spatial soundscapes. The immersive character of the visit results from the simultaneous design of the narrative and soundscapes resulting in an immersive script, the physical proximity between the visitors and the virtual narrator-character creating intimacy, and the use of binaural audio reproduced through headphones enabling for both highly realistic listener-centric audio scene reproduction and an increased listening comfort by isolating visitors from the on-site background noise.

Several strategic assets were incorporated in the mobile app to foster visitors' engagement during the visit. These include an image gallery illustrating some elements mentioned in the narrative, a glossary of the complex terms, bibliographic resources for each audio piece, as well as a gamification aspect in the form of a quest that the visitors are encouraged to complete to help Notre-Dame recover her lost memories. The recovery of Notre-Dame's memories throughout the visit, i.e., the visitors' quest progress, is graphically depicted by a six-petal rose window including medallions, each associated to an individual memory, turning from greyscale to vibrant colours when the associated memory is completed by the visitors.

The visit experience proposed by *Notre-Dame Whispers* will be evaluated through analysing user data collected in an anonymous way and upon agreement with the app Terms of Service and a scientific experiment conducted on-site, comparing different versions of *Ekko of Notre-Dame de Paris* differing in their audio delivery formats, to assess participants' satisfaction level, the reception of the cultural experience, and the learning potential offered by *Notre-Dame Whispers*.

It is hoped that *Notre-Dame Whispers* will find a warm embrace from the international visitors of Notre-Dame de Paris Cathedral before its reopening.

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De nombreux musicologues ont cherché à démontrer le lien et les interactions entre l'espace acoustique et la pratique et l'évolution des répertoires musicaux. Comment ne pas lier, par exemple, la nouvelle construction du chœur de Notre-Dame à la fin du XII^e siècle et ce foisonnement d'expérimentations polyphoniques désigné par l'expression « École Notre Dame de Paris » ? D'autres lieux, comme la Chapelle Saint-Pierre Saint-Paul du Palais de Papes en Avignon amènent les chercheurs à se poser les mêmes questions sur une interaction forte entre architectures, interprétations musicales et techniques de composition. Il en est de même dans le cadre des études, toutes périodes confondues, sur les saintes chapelles ou les grandes églises à coupole de tradition architecturale orientale.

Cet ouvrage rassemble des études présentées au colloque international *Résonances gothiques*. Colloque d'archéoacoustique, organisé du 7 au 9 septembre 2023 au Palais des Papes Convention Center d'Avignon, à l'initiative des projets de recherche The Past Has Ears (PHE) et The Past Has Ears at Notre-Dame (PHEND), avec Sorbonne Université (IReMus et Institut Jean le Rond d'Alembert), l'IUF, le PRISM, et Aix Marseille Université, en collaboration avec Avignon Tourisme, pour faire le point sur les recherches dans les domaines de l'archéoacoustique en lien avec la musicologie, l'histoire et l'histoire de l'art, tout en interrogeant le point de vue des interprètes de chant sacré médiéval qui expérimentent l'acoustique des salles de concert pour trouver des résonances favorables sous les voûtes gothiques.

