Digital & Documentation

V5

From virtual space to information database

edited by
Francesca Picchio

PROSPETTIVE MULTIPLE
STUDI DI INGEGNERIA
ARCHITETTURA E ARTE

PAVIA UNIVERSITY PRESS

Francesca Picchio

edited by

Digital & Documentation

Vol. 5

From Virtual space to Information database

PaviaUniversityPress

Digital & Documentation. From Virtual space to Information database / Francesca Picchio (edited by) - Pavia: Pavia University Press, 2023. - 240 p. : ill. ; 21 cm.

(Prospettive multiple: studi di ingegneria, architettura e arte)

ISBN 978-88-6952-175-1 (brossura)

ISBN 978-88-6952-176-8 (Open Access)

The present publication is part of the series "Prospettive multiple: studi di ingegneria, architettura e arte", which has an international referee panel. "Digital & Documentation: From Virtual space to Information database" is a scientific text evaluated and approved by the Editorial Scientific Committee of Edizioni Pavia University Press of University of Pavia.

The author is available to those having rights which have been unable to communicate for any omissions or inaccuracies.

Edizioni dell'Università degli Studi di Pavia
Via Luino, 12 - 27100 Pavia (PV)
Tel: +39 0382 987743 / 985047
Fax:+39 0382 985047
Email: unipress@unipv.it

EDITING
Francesca Picchio

GRAPHIC PROJECT
Francesca Picchio

PRINTED BY
DigitalAndCopy S.A.S., Segrate (MI)

ISBN 978-88-6952-175-1 (brossura)

On cover: Graphic photocollage by F. Picchio

The volume consists of a collection of contributions from the seminar "Digital & Documentation: From Virtual space to Information database", realized at the University of Pavia on the day of September 19th, 2022. The event, organized by the experimental laboratory of research and didactics DAda Lab. of DICAr - Department of Civil Engineering and Architecture of University of Pavia, promotes the themes of digital modeling and virtual environments applied to the documentation of architectural scenarios and the implementation of museum complexes through communication programs of immersive fruition. The fifth Digital and documentation conference was also the inaugural event of the first Pavia DigiWeek, held from 19 to 23 September 2022 in Pavia.
The event has provide the contribution of external experts and lecturers in the field of digital documentation for Cultural Heritage. The scientific responsible for the organization of the event is Prof. Francesca Picchio, University of Pavia.

This publication is made with the contribution of DICAr, Department of Civil Engineering and Architecture of University of Pavia, through the joint research of the experimental laboratories DAda Lab - Drawing Architecture Document Action and PLAY - Photography and 3D Laser for virtual Architecture LaboratorY.

UNIVERSITÀ DI PAVIA

DIPARTIMENTO INGEGNERIA CIVILE ARCHITETTURA

DAda Lab - Drawing and Architecture DocumentAction

PLAY - Photography and 3D Laser for virtual Architecture laboratorY

The event "Digital & Documentation, V.5" has seen the participation of professors, researchers and scholars from University of Pavia, Politecnico di Torino, University of Rome "La Sapienza", University of Palermo, University of Catania, Politecnico di Milano, University of Ferrara, University of Florence, University of Basilicata, University of L'Aquila, University of Salerno, Gdańsk University of Technology (Poland), Nanyang Technological University (Singapore), Universitat Politècnica de València (Spain), University of Salerno, University of L'Aquila, Lublin University of Technology (Poland), Cracow University of technology (Poland), University of Cordoba (Argentina).

Academic Partners (organizers of Digital & Documentation Conferences)

Università di Pavia – D&D 2018 - 2022

Politecnico di Torino – D&D 2019

Sapienza Università di Roma – D&D 2020

Università degli Studi di Palermo – D&D 2021

Università di Catania – D&D 2023

National and International Academic Partners involved

Università degli Studi Firenze

Università degli Studi Mediterranea di Reggio Calabria

Università degli Studi di Ferrara

Politecnico Milano 1863

Università degli Studi della Basilicata

Università degli Studi dell'Aquila

Università degli Studi di Salerno

Universitat Politècnica de València

Gdańsk University of Technology

Lublin University of Technology

Nanyang Technological University Singapore

UNC Universidad Nacional de Córdoba

Cracow University of Technology

The event is promoted by Unione Italiana del Disegno (U.I.D.)

unione italiana disegno

ANDREA LUMINI

University of Florence

Architect, PhD and Research Fellow in Architecture, curriculum in "Architectural and Environmental Survey and Representation" at the Department of Architecture (DIDA) of the University of Florence.
Since 2018, he has been a research fellow at the LRA Lab of the University of Florence, dealing, within many national and international projects, with activities related to the metric-morphological documentation of Cultural Heritage, its digital representation through different 3D modeling methodologies and the development of virtual systems for management and immersive fruition. His research furthermore focuses on Scan-to-BIM information management methodologies and ICT-related interactive and communicative virtual systems, such as XR, VPL and real-time ArchViz.

FEDERICO CIOLI

University of Florence

PhD and Research Fellow in Architecture at the University of Florence, expertise in historical research, digital survey, and cataloging of architectures and cities. His research focuses on the relationship between Intangible and Tangible Cultural Heritage and on developing strategies for documentation and enhancement.
Since 2017 he has been the technical coordinator for the project "A documentation program for historic shops in Florence". Since 2021 he has been part of the UniFi research team in the European project that was the winner of the Creative Europe 2020 call entitled "AURA - Auralization of acoustic heritage sites using Augmented and Virtual Reality".

05 PROJECT AURA:

ACOUSTIC SIMULATION OF THEATRE HALLS FROM DIGITAL SURVEY TO VIRTUAL RECONSTRUCTION

Abstract

The issue of acoustics is an increasingly debated topic in the fields of digital documentation and Cultural Heritage preservation, especially in contexts such as theater halls, churches, and auditoriums. These acoustic characteristics change over time and thus contribute to structuring the historical memory of a place, playing a fundamental role in the perception and fruition of the built environment. Indeed, the acoustics of an architecture is an intangible consequence of its construction and the design choices made on the materials and furnishing systems that will constitute the truly tangible elements of the Architectural Heritage.
On these theoretical aspects has thus moved the European project AURA – Auralisation of Acoustic Heritage Sites Using Augmented and Virtual Reality, co-funded since 2021 by Creative Europe, whose aim is to explore the potential of auralization – a technique for simulating the acoustics of a given place within models – by combining it with the three-dimensional-visual representations of the virtual environment based on accurate digital surveys.
For this purpose, three emblematic European case studies were thus examined – the Konzerthaus in Berlin (DE), the Teatro del Maggio Musicale Fiorentino in Florence (IT) and the Opera and Ballet Theater in Lviv (UA) – for each of which an appropriate methodology dedicated to digitization and virtual reconstruction was conceived, with the aim of obtaining reliable assets on which subsequent auralization processes could be set and, following these, to develop multisensory, reliable and high-performance 3D models both in terms of graphic rendering and virtual fruition, and in terms of acoustic simulation.

Introduction: the AURA project

The development of modern technologies had a substantial impact on the Cultural and Creative Industries (CCI), which take advantage of its potential to explore new performative horizons, create new business models and attract ever-new and dynamic users [Bertocci et al., 2021]. The COVID-19 pandemic has highlighted the urgent need to develop alternative ways to access to cultural and artistic heritage. The AURA – Auralisation of Acoustic Heritage Sites Using Augmented and Virtual Reality project, co-funded by the Creative Europe call since 2021, aims to explore the potential of auralisation[1] to create immersive virtual experiences that combine both visual representation and acoustic simulation.

The project is designed to deliver an immersive experience where the user can interact with the environment and experience how the perception of soundscape is influenced by architectural space, and how at the same time soundscape influences the perception of the built environment. Acoustic simulation experiences are generally built around a listener, while architectural visualisation experiences revolve around an observer. These immersive experiences stimulate a single sense, thus limiting the user's perceptive possibilities of the represented object. The acoustic of an environment plays a fundamental role in perception. The creation of Virtual Acoustic Environments (VAEs) [Kato et al., 2008] makes it possible to bring back to life the acoustic experience of places that no longer exist, or to compare the acoustic of distant places in a virtual environment [Eley et al., 2021]. Beyond the physical aspect of the acoustic phenomenon, the perception of a site soundscape carries a heritage value that needs to be documented and archived [De Muynke et al., 2021]. This was spotlighted by the 2017 UNESCO resolution 39 C/49, "The importance of sound in today's world: promoting best practices", which complements the concepts and principles of safeguarding that were introduced with the "Convention for the Safeguarding of the Intangible Cultural Heritage" in 2003. Thanks to technology advancements, it is now possible to develop new applications that allow for both audio and visual content integration. AR and VR applications enhanced the user experience, as they allow development of new interaction systems between the user and the virtual experience, creating an immersive system that takes full advantage of the dissemination potential of ArcViz and Acoustic experiences [Borisov et al., 2022].

The AURA project explores three emblematic European case studies: the Berlin Konzerthaus (DE), the Teatro del Maggio Musicale Fiorentino (IT) and the Lviv Opera and Ballet Theater (UA). An appropriate digitisation and virtual reconstruction methodology has been developed for each of the theatres to create reliable 3D models from a graphic rendering and digital accessibility perspective, as well acoustic. Selecting three different case studies

Fig. 1 - The AURA European project, its partnership and the three case studies: the Konzerthaus in Berlin (DE) , the Teatro del Maggio in Florence (IT) and the Solomiya State Academic Theater of Opera and Ballet in Lviv (UA).

from an acoustic, functional, and architectural point of view was essential to define a reliable and replicable methodology. The project analyses a contemporary building, the Teatro del Maggio Fiorentino (2011), to address issues related to contemporary technologies and materials; a neoclassical-style 1980s reconstruction, the Konzerthaus in Berlin (1984), to address problems associated with the combination of different materials, such as reinforced concrete, wood and decorative stucco; and finally an architectural typology present throughout Europe, represented by the Italian-style theatre with the neo-baroque features Lviv Opera and Ballet Theater (1900), which presents the limitations of architectural and decorative structures when it comes to acoustic. The project, completed in December 2022, sets guidelines for the creation of multi-sensory virtual experiences to make the auralisation of cultural spaces easily accessible and applicable in the future. (Fig. 1).

The importance of acoustic in cultural heritage safeguarding strategies

The strategies to investigate and safeguard cultural heritage, both tangible and intangible, lean towards a greater integration and use of acquired data, often heterogeneous and from different research fields. A growing sensitivity towards a more ephemeral and fragile aspects of heritage – such as its acoustic features – leads to the development of new methodological protocols that reinterpret and integrate approaches already consolidated by each individual discipline. The new frontiers of digital surveying, 3D modelling and rendering applied to built heritage allow the recreation of a digital copy of the investigated object, preserving its image over time and making it widely accessible through mixed reality technologies (MR). Similarly, the auralisation processes [Kleiner et al., 1993] – which had been already employed in acoustic design for several years – have been integrated by visually accessible models that contextualise sound experiences. For research projects on acoustic heritage – particularly those that investigate the acoustic of an archaeological site or a damaged or destroyed building – a well-balanced integration of acoustic and visual aspects is necessary[2]. One exemplar is EVAA (Experimental Virtual Archeological Acoustics), an umbrella project that gathers multiple sub-projects on heritage acoustics research, virtual reality and real-time auralisation. Amongst the case studies investigated by the research group coordinated by the Sorbonne University of Paris, that forms part of the Past Has Ears project (PHE 2020-2023)[3] [Katz et al., 2022], is the Cathedral of Notre Dame, then further explored by the Past Has Ears at Notre-Dame project (PHEND 2020-2024) [Eley et al., 2021] [De Muynke et al., 2022]. The acoustics of Notre Dame is considered an essential part of its intangible heritage, particularly as it may have played a fundamental role in the development of musical practices during the Middle Age. The study compares the current internal acoustics, following the fire of 2019, with that recorded by archival acoustic measurements, particularly those acquired in 2015 during an investigation campaign for the virtualisation of the UNESCO heritage site. This comparison also allows for monitoring the effective acoustic correspondence of the restoration project during the construction phase and verifying the accurate restoration of the original atmosphere.

The AURA workflow: developing a methodology for VR and acoustic simulation of theatre halls

As mentioned earlier, the very purpose of the project is to exploit the potential of the three different case studies to define a methodological workflow for VR and acoustic simulation of theater halls that can be replicated and applied at the European level for the virtualization of other venues as well (Figg. 2-3).

This methodological workflow, mostly common to the three cases, included an initial phase focused to digital surveying using terrestrial laser-scanner (TLS) instrumentation – and in one case also through Structure from Motion (SfM) photogrammetry techniques – in order to ensure a reliable metric basis for the next step concerning the 3D modeling of the main halls.

At the same time, a semantic subdivision of the furniture and architectural elements that constitute the main halls, together with a classification of the related constructive materials, was also carried out. Based on this, each material was also classified acoustically through on-site investigations and studies on technical documentation, and properly matched with the specific acoustic parameters[4], in order to develop a parametric acoustic database useful for subsequent auralization processes. Along with these studies, a series of photographic surveys of the various materials present were also carried out for their sampling intended for the creation of photorealistic textures for mapping the 3D models.

The next phase involved the actual virtual reconstruction of the theater hall. This was carried out through specific 3D modeling processes based on the morphometric assets developed from the digital survey and the semantic and materials subdivision. The 3D models were then also subjected to specific mapping and texturing operations in order to optimize their graphical rendering for *ArchViz* simulation.

Next, a preparatory phase to auralization processes was carried out, aimed at creating a parametric and coded database within which the various elements and their respective constructive materials could be associated with the values of the acoustic parameters identified in the preliminary on-site studies.

Finally, the operations related to auralization and virtualization of the theatrical venues – which, however, will not be explored in depth within this paper – were carried out by exploring the multiple potentialities offered by *Unity* platform. Indeed, this Game Engine allows both the creation of virtual and immersive 3D environments and, through a specific plugin, also their auralization.

All of these methodological experimentations thus made it possible to develop an easily replicable workflow for the creation of immersive multisensory VR experiences intended for different types of users. Indeed, the last phase of the project involved a series of testing activities on users in order to verify the actual response and contribution offered by the auralization of 3D models developed according to this workflow.

Fig. 2 - Concept of Aura project. The main hall of the Lviv Opera House depicting the interaction between the two 3D models: on the left the one intended for auralization and on the right the one for visual rendering.

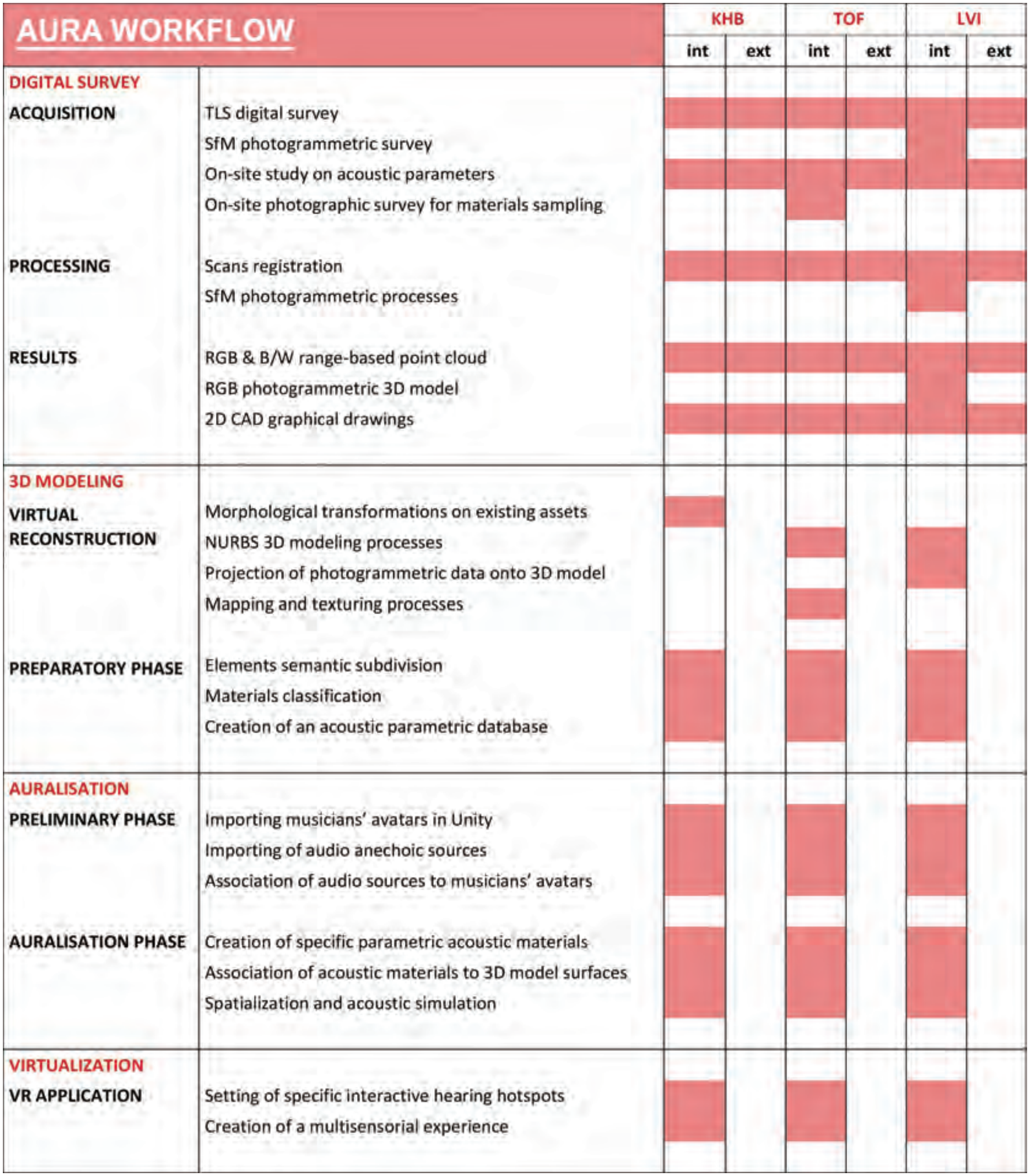


Fig. 3 – Methodological workflow of the activities carried out for each case study.

The digital survey for a reliable virtual reconstruction of the three case studies

The project's first step is digitizing the built heritage through appropriate technologies that ensure a reliable virtual morphometric reconstruction. Specific and different digital survey campaigns were thus planned for the documentation of the three case studies (Fig. 4).

Data acquisition activities for the Berlin Konzerthaus began in September 2021 and included laser-scanner surveys. Two different TLS instruments were used, a *Z+F Imager 5016* and a *Faro Focus*^{M} *70*, both with phase difference technology. Specifically, the first one was used to acquire 220 RGB color scans related to the exterior environments of the Konzerthaus, its foyer and main hall, while the second one was used to acquire 300 B/W scans of corridors, stairwells and service areas (Fig. 5).

Fig. 04 – Digital survey acquisition activities of the three case studies and panoramic views of the colored point clouds of their exterior areas.

Likewise, the digital documentation activities for the Teatro del Maggio Musicale Fiorentino – conducted in early 2021 – involved the use of the same TLSs, through which were acquired respectively 180 RGB color scans of the exteriors, its foyer and main hall, and 110 B/W scans for corridors, stairwells and service areas (Fig. 6).
The digital survey of the Lviv Opera House required instead two different temporal tranches. During the first campaign – conducted as well in early 2021 – geometric data of main hall, foyer, and corridors were acquired using a *Leica C10* laser scanner. Since the 160 scans were captured in B/W, a SfM photogrammetric survey of the hall was combined for color data acquisition. At the end of 2021 a second digital survey campaign was planned, through which missing data from the exterior areas and again some interior spaces were integrated with 160 RGB color scans acquired using a *Faro Focus^{M} 70* (Fig. 7).
All of these laser-scanner surveys have thus provided a large amount of data, which have been subsequently imported and processed within a specific point cloud management software, *Leica Geosystems Cyclone*, through which the main phases of filtering, registration, checking and processing of the point clouds were developed.
The results of this first step have thus provided a set of highly descriptive and reliable three-dimensional metric assets, from which both morphometric and chromatic-material information could be extracted and used for the development of graphical-technical supports necessary for the subsequent modeling and auralization steps.
In parallel to these digital data documentation activities, the methodological workflow included a series of on-site studies on the constructive materials and their acoustic properties, investigating the values of the above-mentioned acoustic parameters necessary for subsequent auralisation processes within the chosen Game Engine plugin.
For this acoustic survey, visual examinations were conducted [Pompoli et al., 2000], through which it was possible to attribute to the acoustically significant materials present in the main hall

Fig. 05 – Colored point cloud of the main hall of the Berlin Konzerthaus developed from laser-scanner surveys.
Fig. 06 – Colored point cloud of the main hall of the Teatro de Maggio developed from laser-scanner surveys

their respective acoustic characteristics – in terms of scattering and average coefficient of sound absorption and diffusion at low, medium, and high frequencies – relying on data found in acoustic technical reports, scientific publications, and acoustic simulation software such as *Odeon*[5] and *Ramsete*[6] [Bartalucci et al., 2018].

Processing of 3D digital-twins for auralization and visualization purposes

The processing and post-production phase of the acquired data was developed by pursuing two complementary and methodologically propaedeutic objectives for the auralization and visualization of the three venues. The first aimed at creating highly descriptive 3D models of the main halls based on the geometric results of the digital survey. The second regarding the semantic subdivision of the various architectural elements to enrich the morphological contents with information relating to the investigated acoustic parameters.

Specifically, regarding the first aspect, the highly reliable metric data obtained through point cloud post-production processes were used to virtually develop the digital-twins of the various case studies following two different reconstructive methodologies (Fig. 8).

For the cases of the Teatro del Maggio and Lviv Opera House, morphometric data from the respective point clouds were extracted and, through a careful data discretization, used for the development of 2D drawings in *CAD* environment in order to create a geometric basis for modeling each element of the main halls. These drawings[7] were then imported within *McNeel Rhinoceros* modeling software where they were used as metric support for the creation of the 3D model of the halls and each of their components[8], exploiting the management and precision potential of NURBS geometries.

For the Berlin theater, on the other hand, an existing 3D model made available by the Konzerthaus institution was used. However, since it did not metrically reflect the real dimensional aspects, specific morphological transformations based on the point cloud data were carried out within *Rhinoceros*.

Similarly to the modeling one, a dual approach was also followed with regard to the mapping methodology of the 3D models developed. For the cases of the Konzerthaus and Teatro del Maggio, surfaces mapping was based on textures created from photographic samples of real materials (Figg. 9-10).

Fig. 07 – Colored point cloud of the foyer and main hall of the Lviv Opera House, developed from laser-scanner and photogrammetric surveys, respectively.

For the case of the Lviv Opera House, on the other hand, a different methodology was tested. The NURBS model developed for the auralization processes, was overlaid with an identical one in the form of a mesh textured by projecting onto it the photogrammetric data developed within *Agisoft Metashape Pro*. In this way, within *Unity*, both the acoustic simulation developed by the auralization of the NURBS model and the realistic graphical rendering of the photogrammetric mesh were guaranteed.

In parallel with the modeling processes, a semantic subdivision of the elements present and their relative material classification was also carried out. After preliminary on-site studies of the materials, all the elements in the main halls were divided and categorized within the 3D models into typological categories, and for each, a different virtual and coded material was associated. This process thus led to the creation of an acoustic database in which each category is associated with a set of ID codes, a material, various numerical-dimensional data, and most importantly, the corresponding acoustic parameters previously investigated (Fig. 11). The values of latter will then be associated with the various surfaces of the 3D models and will become the basis for the development of the auralization processes (Fig. 12).

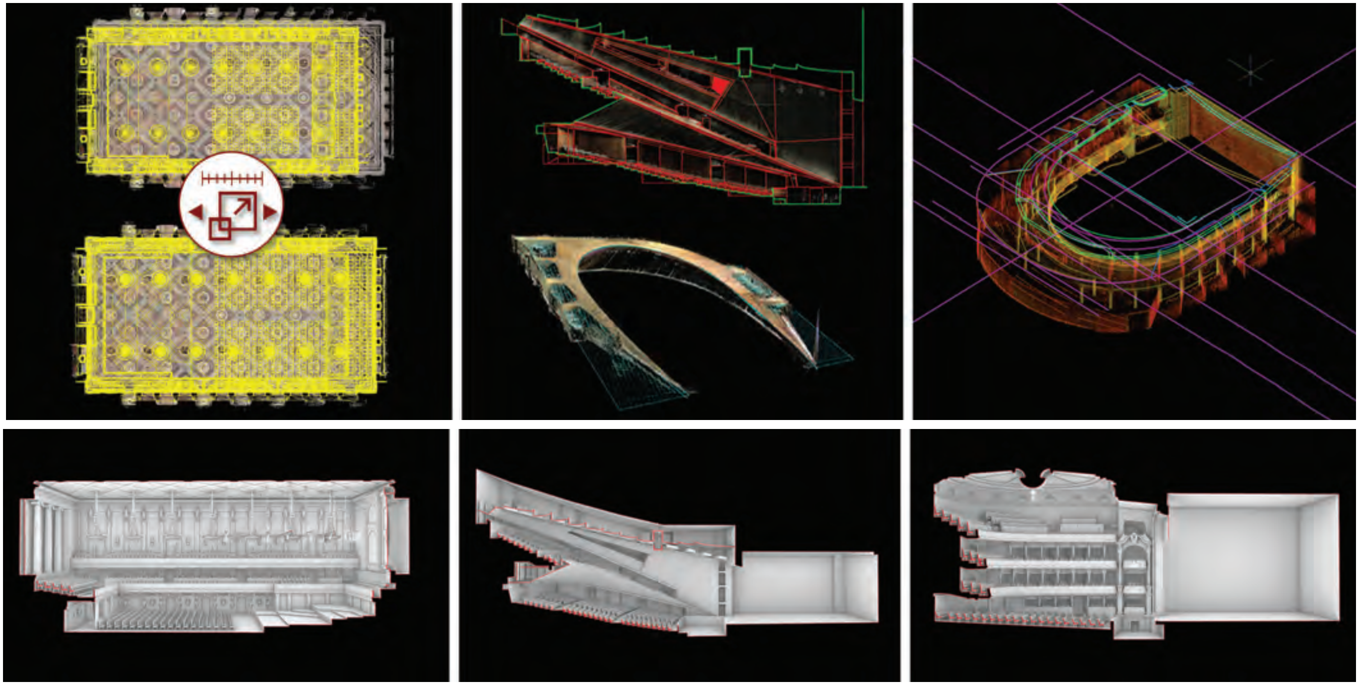
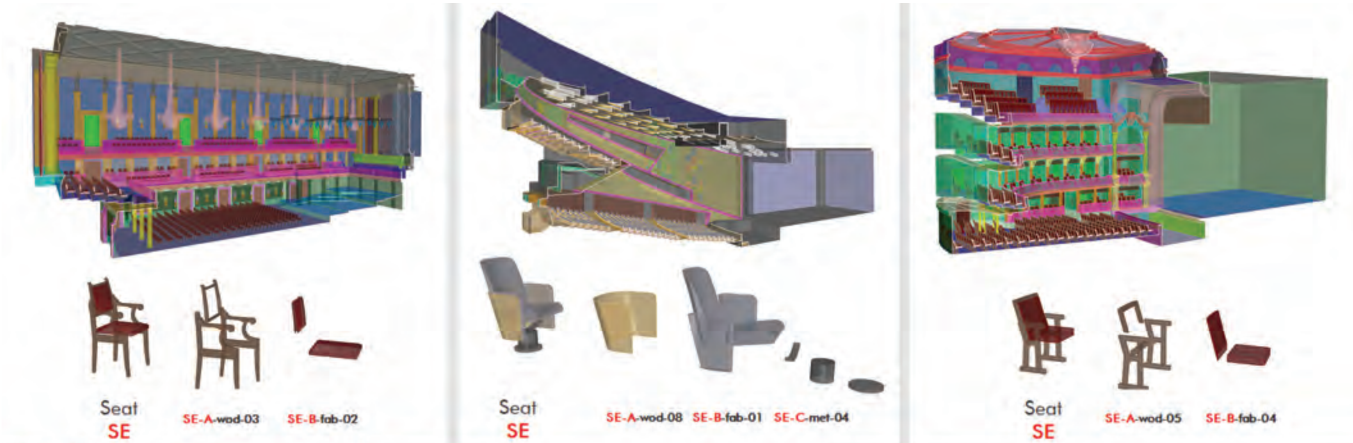


Fig. 08 – Overview of digital processing and different methodologies used for virtual reconstruction of the three case studies.
Fig. 09 – Panoramic view of the textured 3D model of the main hall of the Berlin Konzerthaus.
Fig. 10 – Panoramic view of the textured 3D model of the main hall of the Teatro del Maggio.



ACOUSTIC DATABASE

ID	Element description	TYP	Element Type / Component description	MAT	Material description	Material RGB code	POS	NUM	SRFE	SRFT	LFA	MFA	HFA	S	LFT	MFT	HFT
		A	Stage 01 vertical acoustic background	abg-01	Acoustic background 01	191,191,255		-	-	873,44	0.30	0.50	0.70	0.50	0.00	0.00	0.00
		B	Stage 01 fly acoustic background	abg-02	Acoustic background 02	63,63,255		-	-	374,12	0.50	0.70	0.90	0.50	0.00	0.00	0.00
AB	Acoustic Background	C	Shell 01 wooden surfaces acoustic background	abg-03	Acoustic background 03	0,0,255		-	-	6.72	0.15	0.07	0.05	0.10	0.00	0.00	0.00
		D	Shell 02 slanted walls acoustic background	abg-04	Acoustic background 04	0,0,191		-	-	10.50	0.15	0.07	0.05	0.10	0.00	0.00	0.00

Fig. 11 – Semantic subdivision of the elements and classification of the materials present in the three case studies for the creation of a parametric acoustic database.

Development of multisensorial and virtual experiences

The research required several tests to develop multisensory virtual experiences of the three venues that could simulate visual and acoustic reality simultaneously. The test results identified *Unity* as the most suitable virtual platform for this sort of real-time applications. In fact, in addition to the ArchViz of the developed 3D models, this Game Engine allows through a specific plugin called Steam Audio the development of all auralization processes: importing of audio sources, setting of acoustic materials characterized by the values of the investigated parameters and the association of these with the respective surface materials of the imported 3D models (Fig. 13).

In order to make the visual-acoustic experience more realistic, in each of the three theaters an orchestra

composed of 3D avatars of real musicians was placed, and each of these was associated with its respective audio source recorded individually in an anechoic chamber and making it virtually audible in a spacialising way. In fact, within the Unity-Steam Audio editor, it is possible to set the sound three-dimensionally so that the volume changes with the distance from the sources and with the acoustic properties of the various materials present (Fig. 14).
Thus, the three multisensory and virtual experiences were developed within Unity in the form of VR Apps. In each of the three theaters, even the least experienced user will thus be able to navigate the main hall by moving to specific and defined positions (e.g., front row, balcony, stage...) and decide which instrument of the orchestra should be played by simply activating the respective musician[9] (Fig. 15).
This integrated and immersive approach, in which photorealistic visualization and acoustic rendering are combined with direct and simulated user interaction, aims to significantly develop new ways of communicating and disseminating Acoustic and Cultural Heritage.

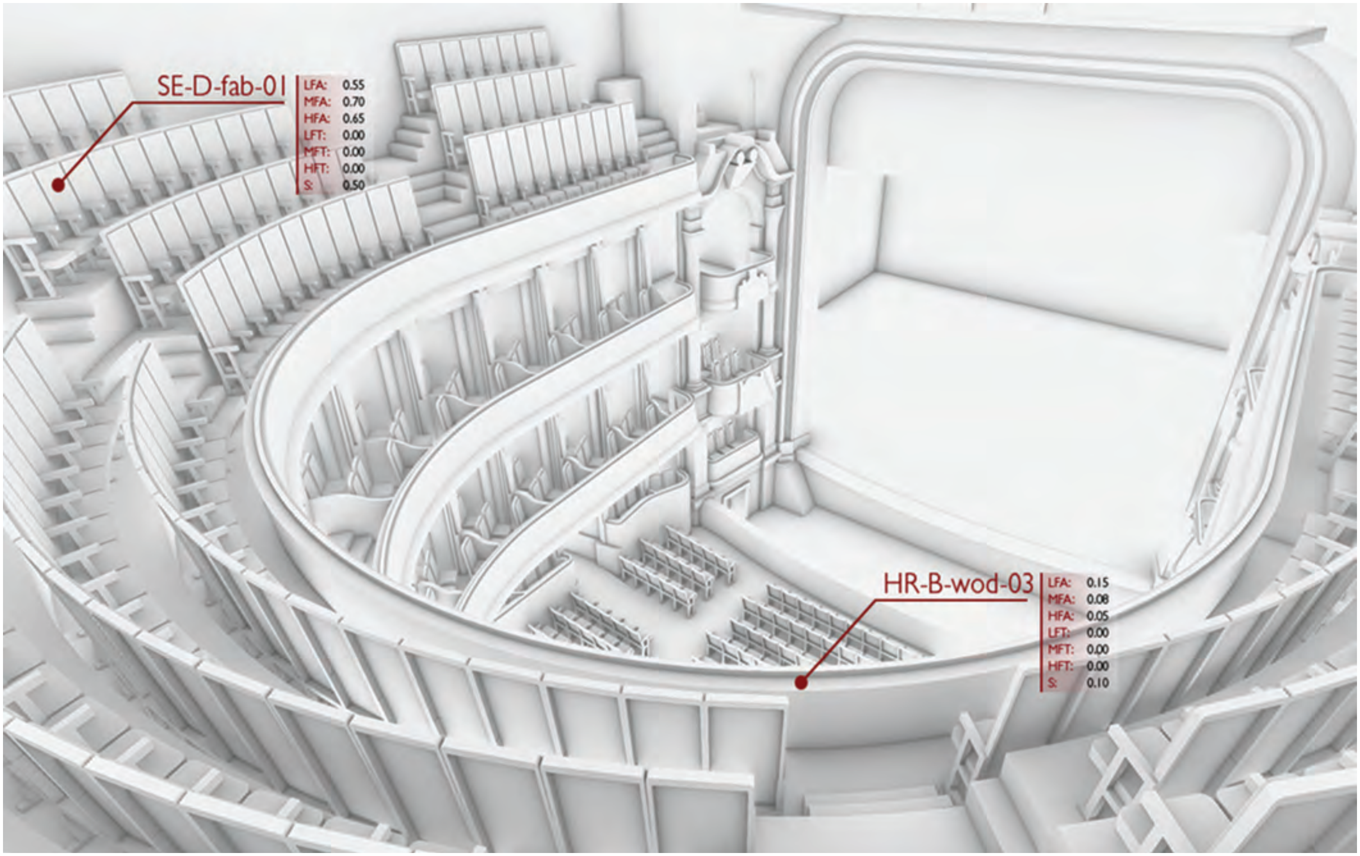


Fig. 12 – Example of acoustic data enrichment within the 3D model of the main hall of the Lviv Opera House aimed at auralization processes.

Conclusions

The results of the AURA project confirmed that precise digital survey campaigns are necessary to develop 3D models that investigate the relationship between space and acoustic.[10] The geometric-morphological aspects of the models, as in the case of the hall of the Konzerthaus in Berlin, deeply influence the sound rendering of the auralised models [Schauer et al., 2022]. Through correct data acquisition and accurate sampling of materials and related acoustic parameters, these tools allow the documentation of both the material aspects of the built heritage and the intangible features related to the soundscape of the investigated entity. Furthermore, using these tools in architectural design offers a unique opportunity to explore and test acoustic in the preliminary stages of the project, thus informing the choice of the best materials and technological solutions both from a technological and an aesthetic point of view. One of the AURA project's objectives is to investigate the possible use of auralised 3D models in the architectural and acoustic design field. The project featured a user testing phase designed by Vie en.ro.se. Ingegneria S.r.L., which collected feedback from musicians, designers and the general public to offer insights on the pros and cons and potential use [Bellomini et al. 2022].

The project also entailed the organisation of a multidisciplinary university workshop on the theme of auralisation, which involved 20 students from the Department of Architecture of the University of Florence. The students took an active part in the "transfer of knowledge" phase, assisting in defining an approach to disseminate methodological steps to a user base of technicians and architects. Notably, the adopted methodologies have proved to be a possible integration in acoustic and digital survey classes, training the Next-Gen of architects and building engineers to be sensitive to issues related to acoustic heritage. These matters are tightly interlinked with BIM (Building Information Modeling) and collaborative design approaches. Together, these disciples create a connection between design and IT skills to create immersive experiences that are beneficial during the design and development phases of the architectural project, as well as in the documentation and protection of the acoustic heritage.

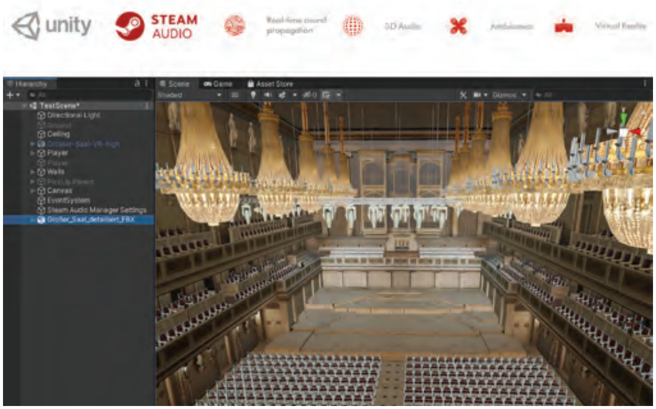


Fig. 13 – Importing main hall models within the Game Engine Unity platform and acoustic processing using the Steam Audio plugin.

Fig. 14 – The three Apps for multisensory experiences and their virtual navigation using VR devices.

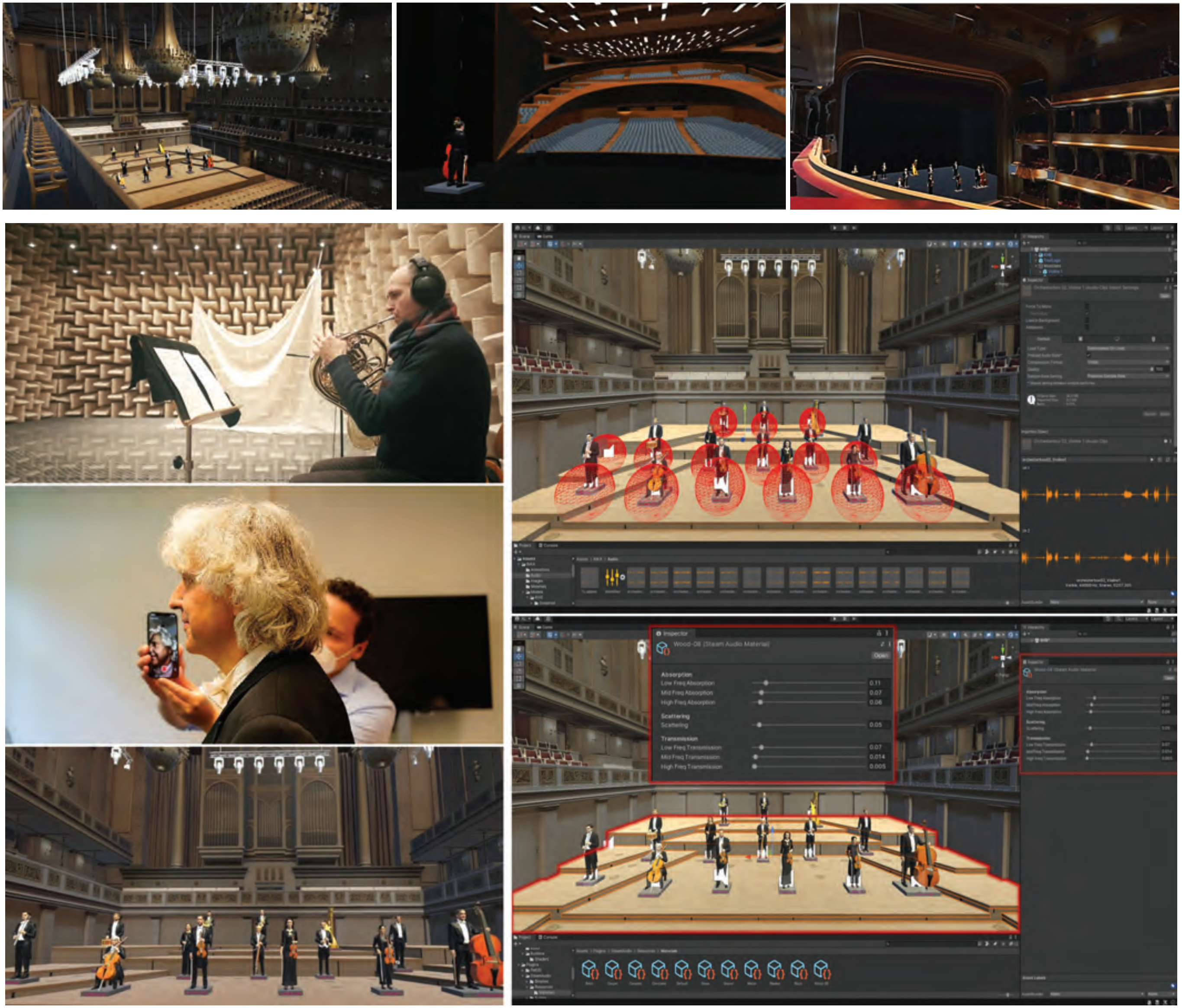


Fig. 15 – On the left, phases of sound acquisition of each instrument, SfM survey of the respective musicians, and insertion of the orchestra within Unity. On the right, auralization processes.

Acknowledgement

Andrea Lumini wrote the paragraphs "The AURA workflow: developing a methodology for VR and acoustic simulation of theatre halls", "The digital survey for a reliable virtual reconstruction of the three case studies", "Processing of 3D digital-twins for auralization and visualization purposes" and "Development of multisensorial and virtual experiences"; Federico Cioli wrote the paragraphs "Introduction: the AURA project", "The importance of acoustic in cultural heritage safeguarding strategies" and "Conclusions"

AURA is a project co-funded by the Creative Europe program led by the Berliner Gesellschaft für internationale Zusammenarbeit mbH (BGZ), in collaboration with the Hochschule für Technik und Wirtschaft in Berlin (HTW), the Department of Architecture (DIDA) of the 'University of Florence (UNIFI) and the Lviv Polytechnic National University of Lviv (LPNU, supported by musical institutions such as the Konzerthaus in Berlin and by marketing partners such as Vie en.ro.se. Ingegneria Srl in Florence, the Lviv Tourism Development Center of Lviv (UA) and Magnetic One of Ternopil (UA).
For further information, see the website of the European project https://www.aura-project.eu

The credits of the activities carried out by the respective technical partners of the AURA project are briefly presented. The HTW team, coordinated by Prof. J. Sieck, was responsible for the auralization of the models and the development of apps for their virtualization and use. The team of UNIFI-DIDA, coordinated by Prof. S. Bertocci, has carried out the activities of digital survey and data processing, as well as the 3D modeling of the theaters. The UNIFI-DIEF team, coordinated by Prof. M. Carfagni, has dealt with the preparatory investigation for the auralization of the values to be assigned to the acoustic parameters. The LPNU team, coordinated by Prof. I. Savchyn, carried out the first digital survey activities, TLS and SfM, of the Lviv case study. The Konzerthaus musical institution provided the textured model of the Berlin theater.

Notes

[1] Auralization is a technique that simulates the acoustics of a real place within a virtual space.

[2] Noteworthy: ERATO projects (2003-2006), focused on the theme of archaeoacoustics for the analysis and comparison of the acoustic properties of ancient Greek and Roman theatres [Rindel et al., 2011]; ECHO project (2013-2018), investigating the issue of acoustics and the integration with digital survey and 3D modelling for the development of virtual experiences [Katz et al., 2019].

[3] PHE – "Past Has Ears" is a research project financed by the JPICH 2019 call, which investigates and develop a methodology for archeoacoustic investigations through heritage sites in France, Italy and UK.

[4] The acoustic parameters considered for auralisation are essentially three: sound absorption and transmission frequencies (low, medium and high) and scattering.

[5] https://odeon.dk

[6] http://www.ramsete.com

7 For some instances with complex geometry portions of the decimated point cloud was imported directly, and from it, through specific algorithms and cross sections, the three-dimensional surfaces were extracted.

[8] For the Maggio case study, in addition to the architectural elements of the hall, the entire acoustic reflection system, such as dispersing panels or acoustic curtains, was also modeled, as well as of the furniture elements, such as the seats, whose wide presence (more than 1700) is extremely relevant in the acoustic study of the hall and, consequently, in the auralization processes.

[9] The orchestra consists of static mesh models made by SfM photogrammetry of real musicians, and includes: two violins, a viola, a cello, a double bass, a flute, an oboe, a clarinet, a trumpet, an harp, a drum, a piccolo flute, a bassoon and a horn.

[10] A number of researches focuses on the direct use of surfaces generated by meshing the point cloud, following a good data simplification process [Foschi, 2022].

References

[1] Bartalucci, C., Borchi, F., Carfagni, M., Luzzi, S. and Busa, L. (2018). The Acoustic Design and Requalification of an Auditorium in a Church and of a Historical Theater, IOP Conference Series: Materials Science and Engineering, 364, pp. 1-8.

[2] Bellomini, R., Bartalucci, C., Busa, L. and Pulella, P. (2022). AURA - Auralisation of acoustic heritage sites using Augmented and Virtual Reality. Project over- view and methodological approach. In PROCEEDINGS of the 2nd Symposium: The Acoustics of Ancient Theatres 6–8 July 2022 Verona, Italy, ISBN *978-88-88942-63-6*

[3] Bertocci, S., Lang, F., Sauter, C., Sieck J. and Shakhovska, N. (2021). "Il progetto AURA: proposta di auralizzazione di alcuni teatri europei per la creazione di paesaggi sonori virtuali," Paesaggio Urbano – Urban Design, 2 (2), pp. 84-89.

[4] Borisov, A., Eiselein, A., Letellier, J., Sieck, J. and Thielen, E. (2022*).* Aural Augmented and Virtual Reality Applications: Best Practices and Challenges. In PROCEEDINGS of the 2nd Symposium: The Acoustics of Ancient Theatres 6–8 July 2022 Verona, Italy, ISBN *978-88-88942-63-6*

[5] De Muynke, J., Baltazar, M., Monferran, M., Voisenat, C. and Katz, B. (2022). Ears of the past, an inquiry into the sonic memory of the acoustics of Notre-Dame before the fire of 2019. Journal of Cultural Heritage Volume 56C (July-August 2022) 130-137], Journal of Cultural Heritage, Volume 56, 2022, Page 130, ISSN 1296-2074, https://doi.org/10.1016/j.culher.2022.06.006.

[6] Eley, N., Mullins, S., Stitt, P. and Katz, B. (2021). Virtual Notre-Dame: Preliminary results of real-time auralization with choir members. Intl Conf 3D Audio (I3DA), Sep 2021, Virtuel, Italy. 10.1109/I3DA48870.2021.9610851 . hal-03371677

[7] Foschi, G. (2022). From Terrestrial Laser Scanning to Room Acoustics Simulation: Recent Approaches to 3D Modelling for the Investigation of Late Antique and Early Medieval Acoustics. In PROCEEDINGS of the 2nd Symposium: The Acoustics of Ancient Theatres 6–8 July 2022 Verona, Italy, ISBN *978-88-88942-63-6*

[8] Kato, K., Ueno, K. and Kawai, K. (2008). "Musicians' Adjustment of Perfor- mance to Room Acoustics, Part III: Understanding the Variations in Musical Expressions," J Acoust Soc Am, vol. 123, pp. 3610–3610, doi:10.1121/1.2934797.

[9] Katz, B., Poirier-Quinot, D. and N. J. Postma, B. (2019). 'Virtual reconstructions of the Théâtre de l'Athénée for archeoacoustic study', Proceedings of ICA 2019 – 23rd International Congress on Acoustics in Aachen (Germany), Red Hook (NY-USA): Curran Associates, Inc, pp. 302–310. Available at: hal: 02354820

[10] Katz, B. F. G., Murphy, D., Farina, A. (2022). PHE: The Past Has Ears project overview. In PROCEEDINGS of the 2nd Symposium: The Acoustics of Ancient Theatres 6–8 July 2022 Verona, Italy, ISBN *978-88-88942-63-6*

[11] Kleiner, M., Dalenbäck, B. and Svensson, P. (1993). 'Auralization – An overview', Journal of the Audio Engineering Society, 11 (41), pp. 861–875.

[12] Lumini Andrea, Cioli Federico (2022). The representation of sound. Digital survey and 3D modeling for the multisensory virtualization of three major European theaters. In Bistagnino Enrica, Battini Carlo (Eds.), Proceedings of UID 2022 - DIALOGUES VISIONS and VISUALITY. 43° International Conference of Representation Disciplines Teachers, 15-17 September 2022, Genova, Italy, pp. 2621-2644.

[13] Pompoli, R., Prodi, N. (2000). Guidelines for acoustical measurements inside historical opera houses: procedures and validation, Journal of Sound and Vibration, 232 (1), pp. 281-301.

[14] Rindel, J.G. (2011). 'The Erato project and its contribution to our understanding of the acoustics of ancient theatres', Proceedings of The Acoustics of Ancient Theatres Conference, Patras, pp. 1–6.

[15] Schauer, S., Shakhovska, N., Sieck, J. (2022). Analysis of Auralisation Techniques for 3D Models of Music Theatres. In PROCEEDINGS of the 2nd Symposium: The Acoustics of Ancient Theatres 6–8 July 2022 Verona, Italy, ISBN *978-88-88942-63-6*.

[16] Schauer, S., Bertocci, S., Cioli, F., Sieck, J., Shakhovska, N. and Vovk, O. (2022). Auralization of Concert Halls for Touristic Purposes. I-com, 21(1), 95-107.

Printed in September 2023 for Pavia University Press
Edition of University of Pavia

The evolution of theories and methods for creating informative or educational digital images of cultural heritage is an ongoing process, anticipating and following technological and instrumental advances. The fifth edition of the conference 'Digital and Documentation' and the present volume, which collects the results of a study day, is part of this debate by showing the use of digital tools for understanding and preserving cultural heritage. Young researchers presented case studies focusing on two current topics: the perception of heritage through virtual design and its renewed management through three-dimensional information systems. Despite their separation, the two parts of the volume intersect through the interaction between virtual and informational systems, prompting new reflections on potential evolutions of representation and opening new avenues for simplified and efficient management of cultural heritage through untapped digital strategies.

ISBN 978-88-6952-175-1
9 788869 521751
WWW.PAVIAUNIVERSITYPRESS.IT