BGZ

White Paper on Auralisation

Promoting immersive sound experiences as innovative classic music performance strategy

D5.3 of the AURA project

AURA

Co-funded by the Creative Europe Programme of the European Union

Project Information

"AURA - Auralisation of Acoustic Heritage Sites Using Augmented and Virtual Reality" (project no. 101008547)

Project Website: http://aura-project.eu

Auralisation – the technique of creating virtual soundscapes in 3D models to provide the same immersive sound experience as the music performed in the real venue. AURA will explore exciting new opportunities that auralisation opens up for music performing arts and their traditional and new audiences.

Publisher & Project Coordinator

BGZ Berliner Gesellschaft
für internationale Zusammenarbeit mbH
www.bgz-berlin.de

Project Partners

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Berlin, 30.01.2023

Co-funded by the
Creative Europe Programme
of the European Union

Inhalt

I. Executive Summary

The Cultural and Creative Industries (CCI) are increasingly moving towards the implementation of modern technologies to explore new commercial horizons and attract new audiences.[1] This impulse has been accelerated in the last two years by the pandemic of COVID-19, which has highlighted the urgency of developing alternative proposals in particular for the future engagement with artistic and cultural heritage.[2]

The motivation behind the project "AURA – Auralisation of acoustic heritage sites using Augmented and Virtual Reality" was the aspiration for the traditional classic-music-based performance sector to level with the emerging sectors of the creative and cultural industries such as games, XR events and digital film, virtual exhibitions, with respect to using cutting-edge technologies to reach new audiences and retain their prospective and existing audiences.

The classic music performance sector has been struggling with a dwindling audience attendance long before Covid restrictions.[3] They also have always heavily relied on public funds for their financial survival.[4] The project, therefore, proceeded to explore the use of immersive technologies as the closest environment to live performances and their all-encompassing experience. The investigation examined all areas linked to the performance: from the creators (music composers, choreographs, designers etc.), the performing artists (musicians, conductors, dancers, actors etc.), the technical support staff, to the managers and directors (marketing, programme, administration) and both the potential and existing audience.

Defying the initial impression that conventional artforms such as classic orchestra, opera and ballet performances are reluctant to think outside the box and experiment with other formats than the traditional frontal performance for a live audience, renowned houses such as the London Philharmonia Orchestra, the Finnish Opera, the Opéra de Paris, the Konzerthaus Berlin, the Mahler Chamber Orchestra, the Royal Opera House, just to name a few, have demonstrated their visionary power with their impressive forward-looking projects.[5]

Although it is still a long way from these pioneer adventures to a daily practice within music theatres and concert halls, classic music programme directors, their artists and technical teams are best suited to drive the technological development in the direction needed for their purposes. These groups are the decision-makers and thus our main target group for this white paper.

We hope that they will follow us on this journey into a future, equipped with a basic understanding of how auralisation of 3D models works, not insisting on the fact that today we are still in the prototype phase, but rather ready to use their imagination for a future vision of what immersive technologies could do for the cultural heritage institutions.

A lot of technical innovations that today are "household commodities" (graphic cards, VR engines, smart phone screens etc.) have been developed and driven by for example game developers wanting to satisfy their own needs as gamers such as improving the fun aspect, the speed of interaction, the number of co-players etc. As proven many times, it is the customer and user of technology who will inspire the development, in the case of the gaming industry, the developers are their own first clients. Thus, it makes a lot of sense for the classic-music-performance sector as the "end user of the technological development" to promote and define visionary uses in order to trigger technological development catering to their specific purposes.

[1] https://bit.ly/3XQu2YV
[2] https://aura-project.eu/media/d4-3_case_study_3_documentation.pdf
[3] https://www.nytimes.com/2014/01/29/arts/music/met-opera-reports-falling-attendance.html ; https://www.classicfm.com/music-news/ageing-audience-france/
[4] https://www.goethe.de/en/kul/tut/21506299.html; https://bit.ly/3jneRXW
[5] https://youtu.be/w0E0v2NsKNw and https://aura-project.eu/media/storyboard_symposium_eng.pdf

With AURA, we wish to encourage the classic music performance stakeholders to onboard this development and not wait for the tech industry to provide them with solutions that lack the understanding of the very nature of that artform, its cultural and creative expression, the interaction with each other (artists) and with the audience.

Introducing immersive and XR technologies into this sector's common practices and strategies requires a lot of know-how and human/financial resources (and funding) and it will certainly take a while until there is any kind of return on investment.

Studies have shown that during the pandemic, there has been an increase in interest in classic music in the much younger age group than traditionally found among classic music aficionados.[6] This opens up a whole new scope of reach-out opportunities as the digital natives have a very different approach with employing their time, socialising, communicating, enjoyment. Pioneering institutions and experimental projects are currently paving the way for innovative means of engagement with the younger audiences in order to be ready when the technology has become financially interesting and their application feasible for music heritage institutions.

With the prototypes developed during the project, AURA hopes to unlock the imagination of music-performing artists, the managers of music venues, and programme directors, to entice them to explore immersive technologies as a vehicle for their visions, and to break down the walls of reluctance towards the still unfamiliar.

The scenario chosen for the AURA project explores the possibilities of simulating the visual and acoustic experience made in a specific space, and in doing so also transgresses the current boundaries. A "*What if you could visit and experience a concert or opera remotely as if you were in the live event, regardless where you actually are physically and at what time of the day you want to experience the event,*" might open up new "touristic" avenues and sell more tickets (e.g. even for the same seat), and an "*Imagine you are not bound anymore by time and physical presence*" could lead to totally new forms of performances, with interaction offering an alternative experience to the frontal divide of the performance on stage. It also holds a lot of opportunities for streamlining the many technical and organisational tasks that are a heavy burden e.g. on the stage occupancy planning.[7]

This document gives a high-level overview of the different results from the AURA project (see https://aura-project.eu/en/results/ and the "Links" chapter at the end of this document), rearranging them to a narrative of the compelling journey and the prospective benefits that immersive technology harbours in the endeavour to trigger the process of preparing classic. music institutions and decision-makers for the future.

[6] Research shows a huge surge in Millennials and Gen Zers streaming classical music. Source: https://www.classicfm.com/music-news/surge- millennial-gen-z-streaming-classical-music/

[7] https://bit.ly/3kYoxsh

II. Combining visual and auditory immersion

Let us start with the basic concepts deployed for an auralised 3D model. Familiarisation with the technology is the first step in engaging with it on "one's own terms", employing one's own expertise, experience and imagination.

Both virtualisation of architecture (existing or planned, buildings or landscapes) in form of visual 3D models and the virtualisation of sound are meanwhile common practices in architectural planning and sound technology, for testing, demonstrating and planning. Virtualisation allows for non-intrusive remote studies.

What is still only in a prototype phase is the combination of both. There is an emerging trend of sound simulation in VR environments, mostly in form of "spatial sound", e.g. in a VR room you can hear those close to you and talk to them without interference from other sounds in the same VR room further away.

Building the 3D models

Auralisation, however, is a big leap from spatial sound. It simulates the acoustic characteristics of a space and the usually large array of different materials and thus different acoustic properties from any point in a space, thus combining spatial sound (closeness to sources) with reverberation of sound.

For our purposes in AURA, we thus needed to create or build a suitable 3D model of each of the three selected venues: the modern building of the Teatro del Maggio Musicale Fiorentino located in Florence and which opened in 2014, the Konzerthaus of Berlin, an old classicism building from 1821 with a colourful history of renovations, and Lviv National Academic Opera and Ballet Theater named after Solomiya Krushelnytska, a renaissance revival building from 1900.

The project investigates a contemporary building, the Teatro del Maggio Musicale Fiorentino, which addresses many of the material and technological problems that can be encountered in new auditoriums and recently built theatres. A building affected by a reconstruction in neoclassical style, the Konzerthaus in Berlin, which allows the AURA team to address the problems relating to the combination of different materials, such as reinforced concrete structures and the wood and stucco decorative elements, typical of nineteenth-century theatres. Finally, the Opera and Ballet Theatre in Lviv (UA) represents a typical example of an Italian-style theatre in the neo-baroque style, an architectural typology present throughout Europe, and which addresses various issues related to architectural and decorative structures and their acoustic responses.

Technical terms:

3D survey: also called digital survey is a fast and accurate way to record the spatial detail of a building. This is done through laser scanner, something also drones are being used. Photography is also an element in the survey. The sum of all scans is also termed a "survey campaign".

Project = the (to be) modelled building

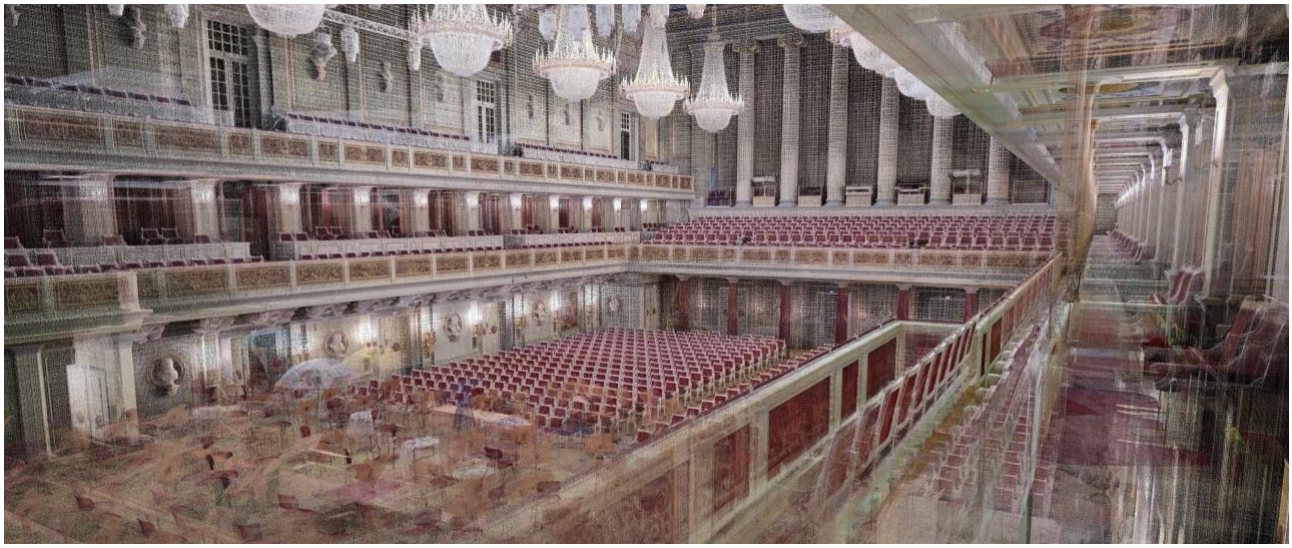
Point cloud: is a collection of many small data points. These points exist within three dimensions, with each one having X, Y and Z coordinates. You can think of these points similarly to pixels within a picture. Point clouds provide high-resolution data without the distortion. To create a three-dimensional point cloud, several scans are needed, and their captured data are then aligned (this process is called "point cloud registration").

Texturing: 3D Texturing is basically wrapping a 2D image around a 3D object and defining how light would affect it. It however is not metrically as reliable as the point cloud method.

In Aura, we tested different methodologies of 3D modelling, however, the most accurate method is the laser scan survey with the metric data aggregated as point clouds.

Digital survey of the Maggio Musicale in Florence with a terrestrial laser-scanner (TLS)

With the point cloud method, one can measure every part of a project to the nearest centimetre which results in a vast amount of data (information). The next step involves verifying the reliability of the developed survey; during this phase any misalignment errors present in the registered point cloud are being checked. These data are then processed and ingested in a database for the subsequent development of the 3D model.



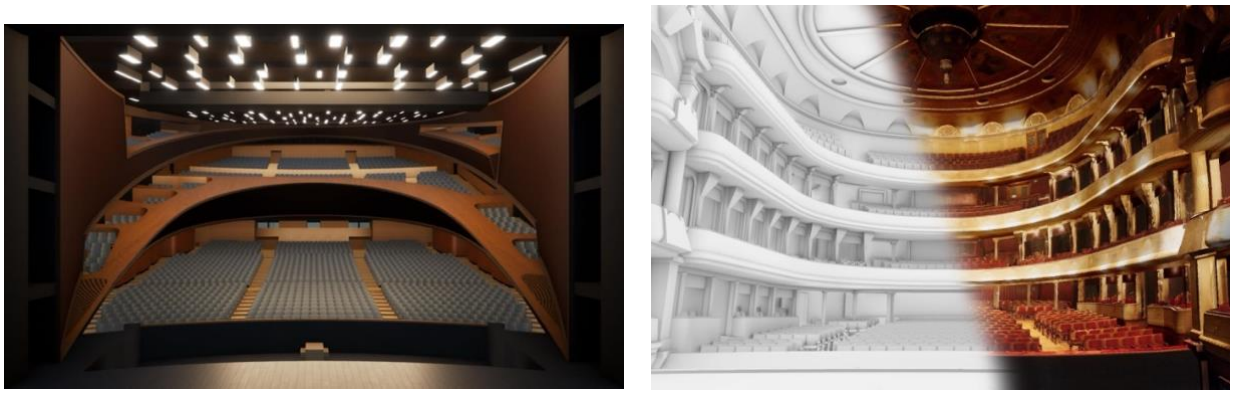
Coloured point cloud of the main hall of the Konzerthaus Berlin

This massive data, however, may be desirable for communication among architects and clients, but they unnecessarily complicate the acoustic model and can lead to lengthy import times, due to the number of surfaces. Even a small object can rise the import time if it consists of many surfaces.

Thus, the point cloud information needs to be reduced to a manageable amount of information, still allowing to capture the acoustic quality of the modelled space.

Decimated point cloud of the main hall inserted within the 3D modelling software

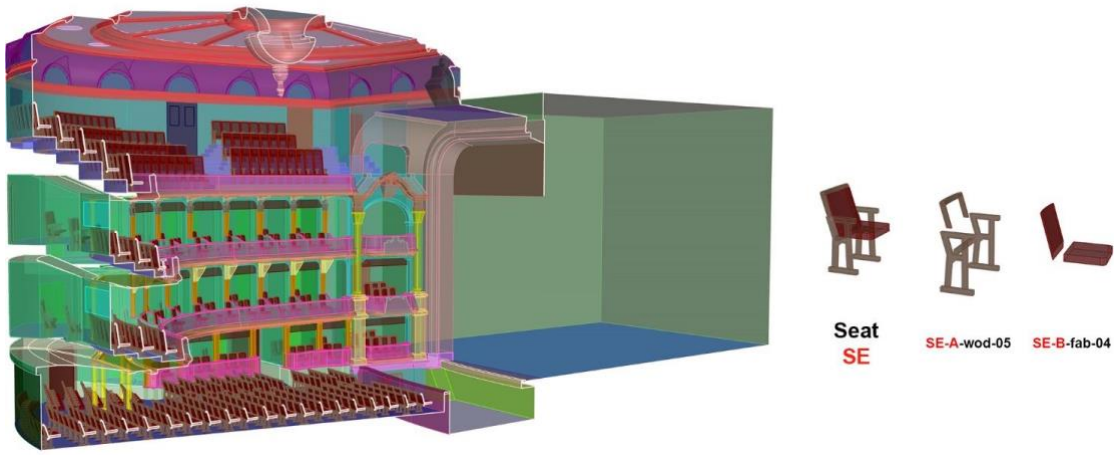
In parallel, a series of on-site studies were carried out on the constructive materials and their acoustic properties, investigating in particular the values of specific acoustic parameters related to them and needed for subsequent auralisation processes. Along with these studies, a series of photographic 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.



Panoramic view of the subdivided and textured 3D model ready for the auralisation processes and for its virtualisation (Opera di Firenze left, Lviv Opera right)

A series of semantic subdivision and material classification processes were executed to create 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.

Different visualisations of the 3D model subdivided into coded component elements (each represented by a different colour) – Theatre of Lviv



This methodological process led to the creation of an acoustic parametric database, in the form of an information table, containing the coding of the various architectural elements subdivided by single material, a count of the number and areas of the multiple instances, a localisation picture of the element, and the acoustic parameters associated with the various materials.

The auralisation of the 3D models

Auralisation is basically the virtual reconstruction of a sound field. Material parameters of objects and their effect on acoustics as well as the overall room geometry are taken into consideration, creating a realistically sounding audio experience. These conditions are stored in a mesh that is combined with a visual mesh, resulting in a visual and acoustical model.[8]

For AURA, we used gaming technologies, i.e. the cross-platform game engine Unity, for exploiting the integration of the point clouds. This allowed reducing the lengthy modelling processes of complex virtual environments, modelling only the elements the user interacts within a multisensory way.

The game engine supports the creatin of virtual and immersive 3D environments. With a specific plug-in, it manages the auralisation of these environments, in our case the three modelled venues. For the auralisation, the system combines the setting of the music sources (the anechoic recordings) and the information on the sound materials and the respective acoustic parameters. The parameters describe the acoustic properties of the different surfaces modelled:

- Absorption values = the amount of sound that a given material absorbs at different frequencies (low, medium, high)
- Transmission values = the amount of sound that a given material transmits at different frequencies
- Diffusion values = the “scattering” that relates to the level of "roughness" of a given surface. High diffusion values mean that sound is randomly reflected sound in all directions, while surfaces with a low value reflect the sound in a specular way, like an acoustic mirror.

In order to modulate the sound according to the properties of the physical surfaces of the modelled space, we need a recording of the sound uncompromised by the acoustic values of the recording studio. This is called an anechoic recording, i.e. without reverberations. Luckily, the Technical University of Berlin has a room equipped for such recordings.[9]

[8] Research within this field has been conducted among others by the Audio Communication Group at the Technical University Berlin, lead by Prof. Stefan Weinzierl. One project was the acoustical recreation of the Teatro Olimpico in Vicenza. Weinzierl, S., Schultz, F., & Sanvito, P. (2011). Die Akustik des Teatro Olimpico in Vicenza. Fortschritte der Akustik–DAGA, 163-4.
[9] see also the video documentary on the recording session: https://youtu.be/Oy81N5kAhYs

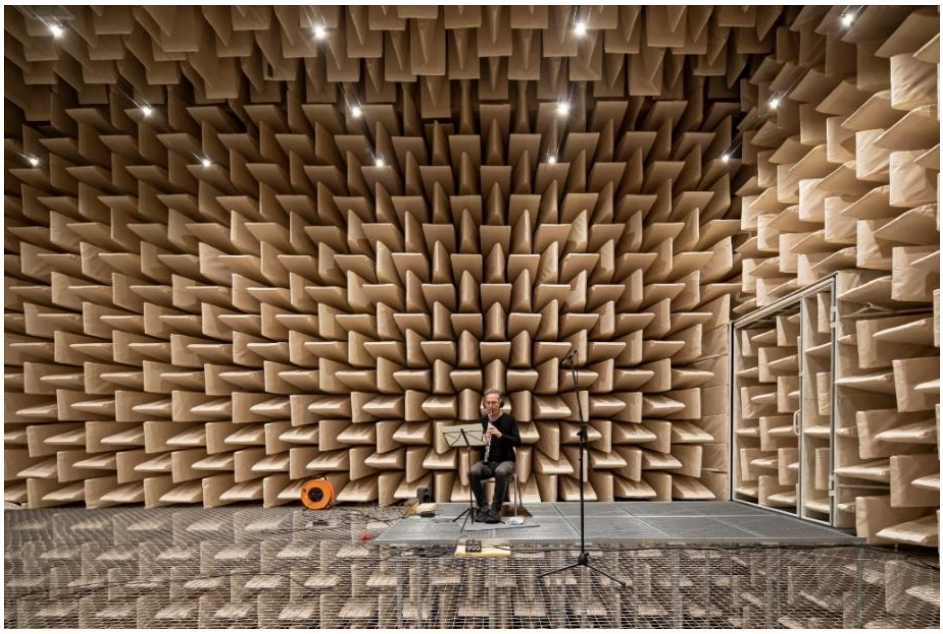


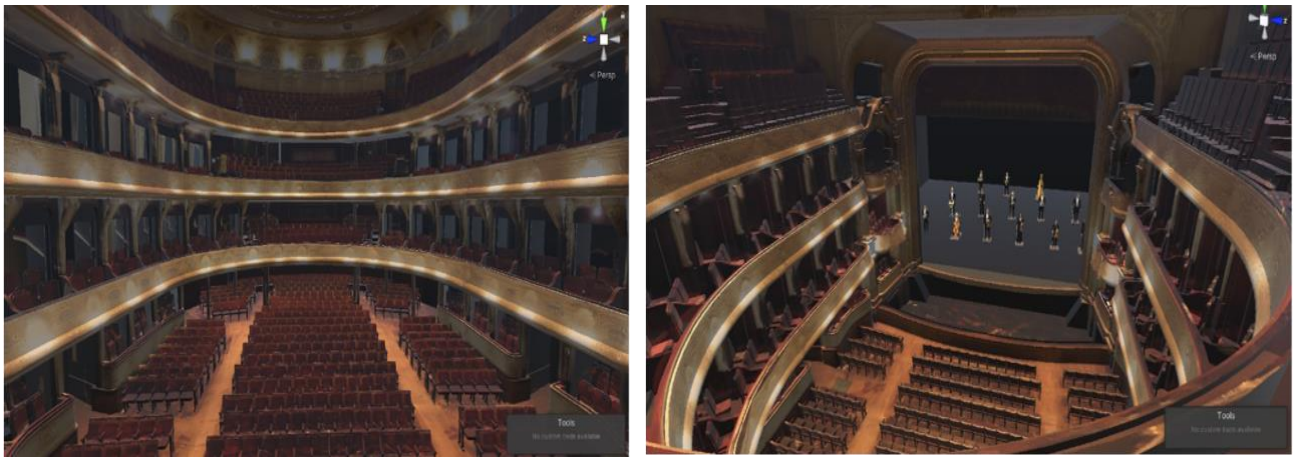
Photo: © Felix Löchner

As a piece of music, we chose a composition by Claude Debussy. The 4th part "Golliwogg's Cakewalk" from "Children's Corner" is especially suitable for this purpose because all instrument groups appear. The approximately two-minute piece was recorded with the following instrumentation with musicians from the Konzerthausorchester Berlin: 1st violin, 2nd violin, viola, cello, double bass, bassoon, clarinet, bass clarinet, oboe, flute, piccolo, trumpet, horn, harp and percussion.

Introducing interaction elements

The first and most basic experience of the auralised model is hearing the music from different positions within the virtual room, giving thus the user the opportunity to experience differences in acoustics from varying seats.

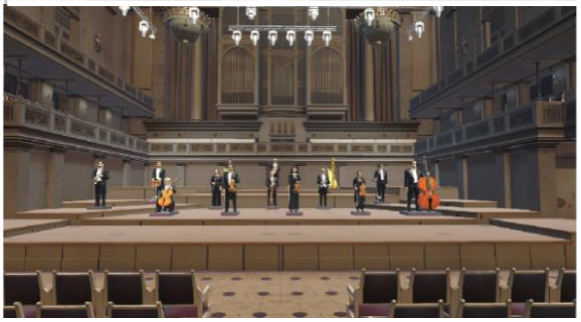
Moving around in VR is not straightforward. To make it possible in these large venues, with balconies, balustrades, steps and rows chairs, we defined so-called “teleporting” points, i.e. selected positions within the space (such as front row, back of the hall, side balcony, central balcony etc. including positions on the stage), to which you could “jump” at your leisure.



Theatre of Lviv: view from the stage and avatars on stage

The other interaction required the use of an avatar for each of the 14 musicians (and thus anechoic sound tracks). For this, the musicians of the Konzerthaus were laser scanned and 3D models were created. Each holding the instrument, they were playing.

Photos: Felix Löchner



Avatars on stage in the KHB model

The recorded music tracks were combined with musician avatars. The interaction allowed to move the avatars around on the stage and to remove individual avatars (and the related sound track) from the stage, thus allowing to understand the role of each individual instrument in the whole composition. For the prototype phase, the avatars were not animated. Naturally, in a more sophisticated application, animated avatars could provide a more realistic experience.

Comparing acoustic qualities

"[…] wine and concert-hall acoustics have a lot in common. They're each characterized by a multidimensional array of perceptual attributes. Evaluating them involves matters of personal taste. When comparing several acoustics or wines, different people concentrate on different aspects of the sound or taste, and they verbalize their perceptions differently"[10]

Tapio Lokki, Head of the Acoustics Lab Dpt at Aalto University (Espoo, Finland), carried out – notably with the Konzerthaus Berlin – an experiment that would make acoustic experiences made in different locations comparable much like wine taster make comparisons by tasting different samples of wines consecutively and in short time frequencies. The experiment was driven by the question "How has the wine industry been able to see past the large perceptual differences between individual tasters to understand the underlying characteristics that contribute to the overall quality of wine? And could their methods be tailored to the perceptual evaluation of concert-hall acoustics to better understand the multifaceted experience of a concert audience?"[11] There are attempts to objectively qualify acoustic quality with ISO Standards,[12] however, "the objectively measured parameters fail to describe the details of perceived acoustics." [13]

"The obvious challenge in applying sensory evaluation to concert-hall acoustics is the requirement of simultaneous comparison of halls. The human auditory memory is too short for listeners to reliably compare concert halls by listening to music *in situ* in different halls. The acoustics of different concert halls—and of different seats in those halls—must somehow be recorded and reproduced in the laboratory so that listeners can switch between different acoustics in the blink of an eye." [14]

[10] Lokki, Tapio: Tasting music like wine: Sensory evaluation of concert halls. In: Physics today. Vol 67/1 (2014). doi:10.1063/PT.3.2242
[11] Lokki, Tapio. Dto
[12] ISO 3382-1: 2009, "Acoustics—measurement of room acoustic parameters—part 1: Performance spaces," ISO, Geneva (2009).
[13] Lokki, Tapio. Dto
[14] Lokki, Tapio: Tasting music like wine: Sensory evaluation of concert halls. In: Physics today. Vol 67/1 (2014). doi:10.1063/PT.3.2242

Lokki's experiment worked with anechoic recordings, replaying the tracks on the stages of different venues with up to 34 loudspeakers distributed on the stage like a real orchestra and a microphone placed on predetermined seat recording the sound 12 m in front of the loudspeakers. This recorded music of nine halls was taken to the laboratory and played back to the 17 listeners who were seated in a dead room within a circle of 24 loudspeakers. The reproduced sound for each hall was completely realistic to anyone who goes regularly to concerts.

The AURA project was also experimenting with the idea of comparability of acoustic experiences in different environments using the same anechoic recording. However, the comparability was extended to the audio-visual perception made when experiencing the music in a specific locality. Rather than sitting in an anechoic chamber while listening to the audio recordings, with AURA the idea was for the full-immersive experience to use Occulus II and very good earphones to experience the comparison. A first impression can be gained here: https://youtu.be/CwRtY3dGAxw.

The study by Marilyn G. Boltz[15] suggests amongst others also that pairing the auditory with the visual has positive effects on musical memory, which in our case would facilitate the comparison between acoustic characteristics of different halls. "One of the most consistent findings in this area is that including visual information with musical stimuli heightens the emotional interpretation and positive evaluation of the auditory information.[16]

One sees how this could be elaborated further with an exact choreography of movements and placement the same for each venue and more advanced interaction features. We are not suggesting that immersive technology and the related virtual experiences are meant to replace the physical live performances. However, as the influence of visual stimuli on the auditory perception is an interesting aspect for further creative explorations into sound experiences enhanced by visual information.

[15] Boltz, M. G., Ebendorf, B., & Field, B.: Audiovisual Interactions: the Impact of Visual Information on Music Perception and Memory. Music Perception: An Interdisciplinary Journal, 27(1), (2009), pp. 43–59. https://doi.org/10.1525/mp.2009.27.1.43

[16] Ebendorf, Brittany: The Impact of Visual Stimuli on Music Perception. (2007) https://bit.ly/3wDuJbM

III. Making a Case for Immersive Applications in the Classic Music Performance and Theatre Sector

Safeguarding cultural heritage

While the innovative experience formats that will arise with the increased familiarity and application of immersive technologies, might still be considered a risk investment into the future, one argument for considering auralised 3D models today is their value from a cultural heritage conservation perspective, a remit that for sure applies to organisations in charge of music venues renowned for their high architectural and acoustic quality.

Intangible Cultural Heritage

With the introduction of the concept of Intangible Cultural Heritage (ICH) by UNESCO in 2003 – as a result of a long debate that began with the Convention on the World Cultural and Natural Heritage of 1972[17] – the way was paved for numerous new more dynamic and ephemeral cultural categories that are essential to preserving the identity of places and cultural diversity. In particular, in 2017, UNESCO introduced the document "The importance of sound in today's world: promoting best practices"[18], highlighting the need for acoustic soundscapes of existing or historical sites – the set of sounds both natural and artificial that characterise a specific place – to be documented, preserved, and scientifically studied.[19]

These acoustic features play a fundamental role in music venues, such as theatres, churches, or auditoriums. The acoustics of architecture is an intangible consequence of its construction, the materials used, and the furniture system, which constitute the tangible aspects of the heritage.

Modern technologies for creating acoustic spaces increasingly exploit mixed reality (MR) technologies – particularly virtual reality (VR) – integrating the sound aspects to the stimuli generated by visual rendering. Some studies have shown that images influence acoustic characteristics[20] and, in particular, that the vision in the perception of auditory space contributes to the correct perception of distance.[21]

Currently underway, the "Past Has Ears" (PHE) project, which began in 2020, aims to document, model, and disseminate the acoustic heritage of three case studies identified for their unique historical, architectural, and heritage characteristics. In particular, the Greek theatre of Tindari is investigated, which no longer has many of its original apparatuses, the Gothic cathedral of Notre-Dame de Paris, which is inaccessible following the disastrous fire of 15 April 2019, and the House of Commons in London, hardly accessible to the public.[22]

A group of German scientists have investigated several archaeological sites for their acoustic heritage. The importance of the speaker in Roman times might well have made acoustics a key driver in the restructuring of the Forum Romanum in Rome.[23]

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[17] Cioli, F. (2020). Il patrimonio culturale immateriale: Un dialogo tra oriente e occidente/The intangible cultural heritage: A dialogue between East and West, Firenze Architettura, Oriente-Occidente rilievi, Quaderni 2020, pp. 114-119.

[18] UNESCO (2017). The Importance of sound in today's world: promoting best practices. In39° UNESCO General Conference, 39 C/49. Paris, 25 September 2017 <https://unesdoc.unesco.org/ark:/48223/pf0000259172>

[19] Katz, B., Murphy, D. and Farina, A. (2020a). The Past Has Ears (PHE): XR Explorations of Acoustic Spaces as Cultural Heritage, International Conference on Augmented Reality, Virtual Reality and Computer Graphics AVR 2020, Springer Professional. pp. 91-98.

[20] Katz, B., Murphy, D. and Farina, A. (2020b). Simulating the acoustics of destroyed or altered amphitheatres, cathedrals, and other architectural sites re-creates their sonic grandeur, Physics Today, 73 (12), pp. 32-37.

[21] Calcagno, E., Abregù, E., et al. (2012). The role of vision in auditory distance perception, Perception, 41, pp. 175-192.

[22] Katz, B. (2020a), dto.

[23] https://www.berlin-university-alliance.de/impressions/20180711-forum-romanum/index.html. See also the project „Analog II. Auralisation of archaeological spaces" running since 2016, a cooperation between Humboldt Universität Berlin and TU Berlin.

Looking at the debates on acoustical ranking and the controversies on the quality of acoustics in modern architectures built expressively as concert halls (e.g. the Elbphilharmonie) and thus most likely to be an architectural and acoustic heritage in the making by their very purpose, it would be interesting to see how acoustical planning could be optimised by auralising the architectural models.

1991, the renowned Berlin Philharmonie designed by Hans Sharoun and inaugurated in 1963, had to be closed for renovation. Plaster had started falling down from the ceiling since 1988. A big debate began on whether to partially renovate or fully modernise the ceiling against fears of losing the acoustic quality: the political consultants argued for a full modernisation was reasonable as the pretend vibration properties were "nonsense", according to them the surface properties were of secondary importance for the reflection of sound sequences. For the site manager of the original building, Wisniewski, the ceiling has "musically matured" and is therefore not replaceable.[24] Perhaps with auralisation, the original qualities could have been preserved?

With the emergence of virtualisation technologies, both modern architectural planning and archaeological reconstructions have been investigating and applying auralisation techniques for their studies. It is just a matter of time that other sectors will take it up to do e.g. live performance simulations.[25] "Spatialisation" is already becoming a common feature in 3D meeting and social spaces, and is quite prominent in interactive video games.

Looming over public projects: Mandatory BIM

What is BIM? BIM is short for Building Information Modelling and designates a process for creating and managing information on a construction project throughout its whole lifecycle. And why would that be relevant for let's say a theatre venue managing director?

BIM is widely used in construction, including restoration and modernisation projects. Political discussions are pushing for a European-wide rule of having to use BIM for public projects with a tender volume over 1 m Euro which might well become mandatory in many countries as of 2025.[26]

Building Information Modelling (BIM) is a highly specialized field of 3D modelling. It involves 3D visualisation of the facility or building to be constructed, but the real advantage of BIM is the amount and depth of data attached to every single component of the structure.[27]

The case we are trying make here is: it makes total sense to invest into a 3D model now as with it you have a variety of projects that you can develop with. You can start exploring with small applications to reach younger generations (see for example the exciting programme "Konzerthaus Digital" of the Konzerthaus Berlin[28]). For example it would facilitate implementation of other technologies currently in the pipeline once they have become more commonly useable, such as motion capture technology.

You could do with it what the Helsinki Opera does with their XR Stage to streamlining stage design and planning and facilitate the collaboration between and "enhance the efficiency of production work and improve communication between the various stakeholders such as directors, set designers, lighting designers and producers".[29]

Or it could be used for your upcoming renovation and modernisation project. Having it ready would then economise on time and funds. Auralisation techniques, including binauralisation, could be applied to improve the acoustics of a hall. There have been complex projects carried out with improving (i.e. prolonging) reverberation time, e.g. with the Staatstheater Augsburg (intelligent loudspeaker system within the constraints of a listed building) or Staatstheater Darmstadt (refurbishment with new material modules).[30] For

[24] "Einige wollen die »heilige Kuh Akustik« schlachten. TAZ article from 5.2.1991 https://bit.ly/3HI72p2
[25] See the cutting-edge research done by IRCAM: Sound Music Movement Interaction | IRCAM
[26] In Which Countries Is BIM Mandatory for Public Projects? | ArchDaily. It has been mandatory in Denmark since 2007, in Sweden since 2010, in the UK since 2016, in Spain since 2018 und in Italy since 2019. See: O8_EN_final.pdf (europa.eu) p.2
[27] Differences between 3D Modeling, CAD, and BIM Explained | Cad Crowd
[28] Konzerthaus digital – Konzerthaus Berlin
[29] XR Stage - Opera beyond
[30] www.singer-akustik.de – https://aura-project.eu/media/storyboard_symposium_eng.pdf

such types of architectural interventions, a model, and more so an auralised model, would prove very beneficial in the planning phase, minimising risks and maximising the quality of planning.

While waiting for a market-ready auralisation technique, commissioning a 3D model early on is a sensible measure in view of safeguarding the architectural heritage against disaster (fire, war, etc.) and protect it while modernising or refurbishing the building.

New creative practices

Auralisation of 3D models or VR environments is still in its development phase with three big challenges to yet be solved:

- Dependence on anechoic recordings, isolating the individual musicians from the group dynamic of the orchestral performance, is very time intensive and thus expensive.
- Lengthy modelling and rendering processes even when reducing the material properties data, the teleporting points and working with little interaction.
- The fact that the assessment of the quality of acoustics of a concert hall remains a basically subjective judgement. For different assessments a full house versus an empty house to mark the difference in reverberation during the live performance with an audience versus rehearsals with empty seats.

Rehearsals and live performances

“There’s no objective way to determine the best acoustics for concert halls, though most people agree on the basics.”[31] Leo L. Beranek, an acoustics legend who has published several rankings of concert halls based on interviews conducted around the world,[32] determined, however, that the consensus in the ranking of "superior acoustics of the hall are due to its rectangular shape, its relatively small size, its high ceiling with resulting long reverberation time, the irregular interior surfaces, and the plaster interior."[33] This pertains to concert halls built up to 1910s.

“Since the advent of the Berlin Philharmonie Hall in 1963, architects and owners have often placed beauty and novelty of architecture above acoustics.” [34]

The modern architectural shapes and space organisations (e.g. surround seating) have led to multiple debates on the quality of the acoustical properties. For example two consecutive performances of Gustav Mahler’s “Lied von der Erde” performed within a fortnight, first by Jonas Kaufmann and then by Andreas Schager, entailed two very different assessments of the quality of the Elbphilharmonie. One reason could have been the different placement of the tenor (in Kaufmann’s case, he was on the front the stage, while Schager was placed on a pedestal further back) resulting in a difference in balance between vocals and orchestra. Kaufmann claimed that amongst others the wall material used was at fault: wood instead of gypsum fibreboard would enhance the acoustics.[35]

As the audience is an important factor in the reverberation of sound, it is not always possible to determine best placements of instruments and vocals during rehearsals. Elbphilharmonie’s acoustic designer Yasuhisa Toyota argues that there is a learning process in the sound experience of unconventional spaces. It is a long

[31] “The 10 best-sounding concert halls in the world”. In: Insider. 5.10.2016. https://bit.ly/3Dr92Q5

[32] Beranek, Leo L.: Concert Halls and Opera Houses. Music, Acoustics, and Architecture. 2003. https://amzn.to/3Y8PI2c

[33] “The 10 best-sounding concert halls in the world”. Dto.

[34] Beranek, Leo L.: Concert hall acoustics: Recent findings. In: The Journal of the Acoustical Society of America 139, 1548 (2016); https://doi.org/10.1121/1.4944787 - This author conducted interviews over a period of 40 years (1960–2002 and made questionnaire surveys of over 150 conductors, music critics, and concert aficionados in an effort to determine how well-known concert halls rank acoustically.

[35] Stäbler, Marcus: Debatte um Elbphilharmonie. Akustikdesigner: Musiker müssen den Saal verstehen. In: Deutschlandfunk. 25.02.2019. https://bit.ly/3Jopg06

process but will ultimately result in an enhanced quality of the performances.[36] This resonates with architect Wisniewski's take on the "musical maturity" of the Berlin Philharmonie (see footnote 16).

These challenges raise the question whether an auralised model of the respective concert hall would not facilitate better judgement in placement of vocals and instruments, or with the reflectors and other acoustical manipulation elements, just as the XR stage from the Opera Helsinki project would do for the stage arrangements.

If one spins the idea further, one could imagine rehearsing remotely in the virtual venues, e.g. in preparation of a live concert in a far-away venue or as a virtual testing before renting a hall for a guest performance or individual musicians rehearsing on their in the virtual venue with recordings of the other instruments, like a simulated group rehearsal.

Let us venture into a future when auralisation is a commonly used technology in virtual environments (metaverse) with real-time rendering and a simple way of creating anechoic recordings, perhaps a technology that "extracts" the echo of any recording dispensing with the lengthy and solitary process of individual track recordings in an anechoic chamber: think about the innovative space opening up creative opportunities, ballet in fantastic virtual environments, opera in historical or fairy-tale settings, experiments with non-frontal performances, unconventional music or dance education features.

Pushing the boundaries of hybrid performance modes: the ambitious "Dream" project[37] - – A live, online performance set in a virtual midsummer forest using volumetrically capturing and motion capture technologies, with XR technologies, game engines and game technologies for sound and visual design. "We wanted to give the performer musical superpowers."[38] Each performer had a related instrument that would sound in correlation with their body movements. "The orchestra should be part of creating new arts.[39]

Having opened door to these new artistic, we won't have long to wait for an abundance of creativity to be ignited.

Interaction with the audience

Of all the future scenarios for innovative creative production that come to mind, those involving and interacting with the audience are the most compelling. Being able to walk among the orchestra musicians or opera actors or look over the shoulder of the conductor are perhaps the first that come to mind.[40]

"[…] data suggest that the decline in attendance among the young and minorities is not due to an unfamiliarity with or dislike of classical music, but to the concert setting itself."[41]

Another artistic avenue is glimpsed at with pioneer projects in co-creation such as "Spatial encounters" by DTHG where the audience and musicians co-create a soundscape, the audience stimulating sound by their body movements, and musicians providing impulses and moods to the live performative interplay. [42]

Exciting projects[43] like the immersive installation "Laila" (Opera Beyond, an initiative by the Finnish National Opera and Ballet)[44] using AI and motion tracking devices, "Beethoven's Fifth" (London Phiharmonia with Google) and "Mahler's Third" (London Philharmonia) using binaural recording, ambisonic microphones and 3D

[36] Stäbler, Marcus. Dto
[37] https://bit.ly/3HHfmWj
[38] Quoting Luke Ritchie at the AURA-Panel" Glimpsing the Future of Immersive Sound Experience: https://youtu.be/w0E0v2NsKNw
[39] Luke Ritchie at the AURA-Panel" Glimpsing the Future of Immersive Sound Experience: https://youtu.be/w0E0v2NsKNw
[40] Mahler Chamber Orchestra with their Future Presence projects are exploring this merging of audience and orchestra: https://www.mahlerchamber.com/concerts/tours/156
[41] Kolb, Bonita M.: The effect of generational change on classical music concert attendance and orchestras' responses in the UK and US. Cultural Trends. (2001) 11. 1-35. 10.1080/09548960109365147.
[42] DTHG:Hybrid-real stages. https://digital.dthg.de/en/projects/hybrid-real-stages/; https://youtu.be/-DQGpIE-sDk
[43] See also the Aura-Panel recording for the presentations of some of these pioneering projects: "Glimpsing the Future of Immersive Sound Experience. 2022. https://youtu.be/w0E0v2NsKNw
[44] https://operabeyond.com

video technology[45] and technologies such as tracking someone's movements to create sound and music (e.g. by Reactional) allow a non-musically experienced audience to meaningfully engage with music.

To quote Luke Ritchie once more:

> *It is important to make the orchestra visible to audiences beyond the concert hall… We're not looking to replace the concert hall. That will always be the final destination…Picking up the audience member and putting them inside the orchestra, wrapping the orchestra around them. using immersive technologies to allow people to explore and be involved in orchestral music in a different way. Orchestral music is so well suited to do that, it is such a great medium for that because it is so dense and layered.* [46]

The project "Umwelten"[47] by the Konzerthaus in cooperation with composer Mark Barden and visual artist Julian Bonequi also explored interaction between music and audience to co-create soundscapes: designed as a game, 30 creatures can be ferreted out in various portals. By tapping on them, users can make them produce sounds and also combine them with one another to create an individual composition that can be recorded and shared. Like many others, the Konzerthaus Berlin is aware of social and societal change in both their traditional and their prospective/potential audiences.

AURA engaged with the visitor through the option of moving and removing the instruments (represented by the avatars) and through being able to teleport onto the stage and thus get a listening impression that a physical visit wouldn't allow. The interaction was offering the learning effect of honing one's hearing skills by trying to detect the differences when removing or moving instruments.

Reach-out to new markets and audiences

Certainly, one of the motivations next to the new creative opportunities and modern cultural heritage preservation is the retention and attraction of both current and new audiences. Creating interactive cultural and artistic formats is a promising way to do so. There is also a notion to have to keep up with the digital marketing schemes in order to be competitive, if not commercially then in the sense of competing for attention.

We have described several future scenarios for a time in the near future where the technology – which we all know is rapidly evolving – will have reached an implementation and economic level that will make it attractive for cultural organisations to work with these technologies. Certainly, a lot will depend on the "ease" of virtual sound modelling, but even more on the equipment for entering VR worlds, some very light version of the Occulus for example.

Imagine then trains or airplanes offering an immersive concert or opera experience as they used to do with screens on the back of the seat in front of you and instead of offering earphones (as one used to do in airplanes), they would offer the light device for VR viewing. Companies would purchase their auralised events for their customer entertainment programmes.

Mobility has been under scrutiny since Covid, not only for environmental, health or economic reasons but also because it instigated a new behaviour where wasting time to get from A to B is reviewed critically. And then there is the target group that is immobile. In particular music theatre and classic concerts have a large community of aged persons for whom travelling, mounting steps etc. is about to be no longer possible. The Opera in Paris has carried out a project with old people's home, handing out Occulus sets for them to view in 3D a ballet performance.[48] It could also be an offer in hospitals and other institutions where people are immobile.

Already we have operas filmed for the cinema. Auralisation would greatly enhance this experience. One can also think of something along the lines of an escape room or a CAVE (Cave Automatic Virtual Environment), an

[45] https://philharmonia.co.uk/what-we-do/digital-immersive/immersive/

[46] Luke Ritchie at the AURA-Panel" Glimpsing the Future of Immersive Sound Experience: https://youtu.be/w0E0v2NsKNw

[47] https://www.konzerthaus.de/en/umwelten

[48] https://youtu.be/41HudlBVlu4 and https://www.operadeparis.fr/en/my-committed-opera/from-the-stage-to-virtual-reality

immersive virtual reality environment where projectors are directed to between three and six of the walls of a room-sized cube which could be used as an event space for a group experience.

It could also cater for new behaviours and preferences such as choosing one's own time "to go to the opera", and not feel the social pressure of the "distinguished clientele" and the related dress code (even though this is not really the case, mostly only opera-goers are of that, not those who don't go, they still carry this image).

As with many "reproductions" of the "real thing", an auralised version could act as catalyst for going to the real venue and the live performance.

Ticket marketing is also a consideration: first of all, one could "sell" the best seats infinite times in the VR world, but more interestingly, people could check whether the more expensive real seats are worth their money, i.e. whether they hear a difference in the auralised version. On the other hand, as Hans-Peter Tennhardt, the acoustics engineer of the Gewandhaus Leipzig said, there is not only formula for the best seat.[49] Some wish to watch the conductor, then a seat behind the orchestra is the best (in surround structures like the Gewandhaus), some wish to experience in particular the strings, then they would best place in the front rows facing the orchestra, for those who prefer a well-balanced mix of the sound, a seat in the first or second third of the hall would be best, depending on how the orchestra is placed, there might be a benefit on sitting on the sides, if e.g. one wants to what the piano play. [50]

This are just a few of endless idea that will evolve and be generated the closer the "future" envisaged here gets.

[49] The AURA partner LPNU (Lviv Polytechnic National University) made a study using AI for seat preferences: see Annex II https://aura-project.eu/media/d4-3_case_study_3_documentation.pdf

[50] Goertz, Wolfram: Magie der Akustik. In: Rheinische Post. 25.2.2017. https://bit.ly/3HDLwBU

IV. Conclusion

In the past years, in particular the UK has been extremely active in studying the impact of digital and immersive technologies on audiences:

> *Innovate UK's recent Knowledge Transfer Network report on The Immersive Economy in the UK estimates that Britain has around 1,000 immersive-specialist companies employing around 4,500 people and potentially representing as much as 9% of global market share. UK Creative Industries have a huge amount to contribute to this emerging immersive sector, not least because many of the skills involved are derived from different corners of this thriving, diverse and crucial part of the economy (such as film, TV, games, visual effects, etc).*[51]

It is obvious that when talking about the role of CCI in the advancement and shaping of immersive experiences and development of technologies, seldom the "traditional" sectors such as classic music, opera, theatre, ballet, museum or book publishing are meant. The sample of participants for the Digital catapult report mentioned above, showed that around 92% of the participants went to a museum in the 12 months prior to the trial (pre-covid), 87% to cinemas, but only 14% to the opera.

If the classic music performance sectors do not want to be left behind the "digital turn", they need to bring more musicians and "traditional" music producers in that process of experimenting with immersive technologies, as "immersion" is the very core experience of the performance sector. For this, the creative teams need to build cross-disciplinary teams - from theatre directors to game designers.

When asked in the AURA panel about whether they perceived a reluctance within the classic music sector to open up for experimental projects with immersive or XR technologies, all speakers agreed that they found that "Opera, ballet, orchestras are more open to experiment than the "commercially" driven "popular music" sector. They are better set to take risks and push the change"[52] as not so driven by mainstream opinion and market-sourced revenue.

There is a real opportunity here for the sector taking the lead in sounding out the so far only glimpsed vast scope of creative and co-creative expression.

[51] Lessiter, Jane et al: User Experience and Audience Impact. A report produced by Nesta and i2 Media Research for Digital Catapult. (2018). https://bit.ly/3joVKwP
[52] https://youtu.be/w0E0v2NsKNw

V. Links

The Modelling

Anechoic recordings with the Konzerthausorchester Berlin

https://www.youtube.com/watch?v=v4P64Yh9gB4

Konzerthaus Berlin

3D model – Documentation

https://aura-project.eu/media/aura_d2.1.pdf

Auralised 3D Model – Documentation

https://aura-project.eu/media/d2.2_auralised_model_of_the_berlin_music_venue_1.pdf

Auralised Model – Video

https://www.youtube.com/watch?v=fF_AI5-i_jk

Maggio Musicale – Opera di Firence

3D model – Documentation

https://aura-project.eu/media/aura_d3.1.pdf

Auralised 3D Model – Documentation

https://aura-project.eu/media/aura_d10_auralised_model_of_the_florence_music_venue.pdf

Auralised Model – Video

https://www.youtube.com/watch?v=rlq4Ip8WGlg

Lviv National Academic Opera and Ballet Theatre

3D model – Documentation

https://aura-project.eu/media/aura_d4.1.pdf

Auralised 3D Model – Documentation

https://aura-project.eu/media/d4.2_auralised_model_of_the_lviv_music_venue.pdf

Auralised Model – Video

https://www.youtube.com/watch?v=_mCsLO7H1ss

The “comparison” of the three auralised models - video

https://www.youtube.com/watch?v=CwRtY3dGAxw

Educational

Three video tutorials for different target groups (youtube, click on subtitle choices)

TUTORIAL Children part 1 720p 221025

https://www.youtube.com/watch?v=YyapxmRq5MM&list=PLx34xG1DHyRMcPqP-CJsd9UN5dj-EeZgG&index=2&t=85s

TUTORIAL Children part 2 720p 221020 2

https://www.youtube.com/watch?v=w8CzG7pDeb8&list=PLx34xG1DHyRMcPqP-CJsd9UN5dj-EeZgG&index=3&t=1s

https://youtu.be/w8CzG7pDeb8

TUTORIAL Children part 3 720p 221025

https://www.youtube.com/watch?v=WGA4xCkSPfc&list=PLx34xG1DHyRMcPqP-CJsd9UN5dj-EeZgG&index=4&t=2s

TUTORIAL General Public 720p 221031

https://www.youtube.com/watch?v=ZgjtX5pIeW4

AURA TUTORIAL Technicians ENG

https://www.youtube.com/watch?v=-krsqQhDRo4

Case Studies

Case Study on Auralisation Benefits for Stakeholders

https://aura-project.eu/media/d2-4_case_study_on_auralisation_1.pdf

Case Study on Future Scenarios (Audience and Marketing focus)

https://aura-project.eu/media/d4-3_case_study_3_documentation.pdf

Technical Publications

Technical description of the 3D modelling of the three venues

https://aura-project.eu/media/aura_d3-2_technical_description_of_the_3d_modelling_of_the_three_venues.pdf

Documentation of auralisation techniques for aural production and experience

https://aura-project.eu/media/d2-3_documentation_of_auralisation_techniques_for_aural_production_and_experience.pdf

Supporting documents for tendering processes

https://aura-project.eu/media/d4-4_supporting_documents_for_tendering_processes.pdf

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Italy

www.unifi.it

www.vienrose.it

Ukraine

https://lpnu.ua/de

https://lviv.travel/en

https://magneticone.com.ua