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Digital survey and 3D modeling to support the auralization and virtualization processes of three European theater halls: Berlin Konzerthaus, Lviv Opera House, and Teatro del Maggio Musicale in Florence. A methodological framework

Stefano Bertocci[1]; Andrea Lumini[2]; Federico Cioli[3]

[1] University of Florence – Department of Architecture (DIDA), Italy, stefano.bertocci@unifi.it
[2] University of Florence – Department of Architecture (DIDA), Italy, andrea.lumini@unifi.it
[3] University of Florence – Department of Architecture (DIDA), Italy, federico.cioli@unifi.it

ABSTRACT

This paper shows three different approaches to the issue of morphological/dimensional survey of theater halls, aimed at creating a 3D model to support the processes of auralization and immersive virtualization to create a reliable basis for the ArchViz and acoustic auralization processes. The chosen three European case studies of the Konzerthaus in Berlin, the Opera House in Lviv, and the Teatro del Maggio Musicale in Florence provided the fundamental basis for the development of the AURA project.

Keywords: AURA, digital survey, 3D modeling

1. INTRODUCTION

The paper presents some results of the activities within the European project AURA - Auralisation of acoustic heritage sites using Augmented and Virtual Reality - co-financed by the Creative Europe program. The research proposes the construction of multisensory virtual 3D models to support and encourage new opportunities to use and disseminate Cultural Heritage for Cultural and Creative Industries (ICC). The work provides the construction of multisensory environments related to three major European theaters seen as case studies: the Konzerthaus in Berlin (DE), the Lviv Opera House (UA) and the Teatro del Maggio Musicale Fiorentino in Florence (IT). Finally, by creating models for immersive experiences in VR, the project aims to integrate the visualization of the architectural space of the three case studies with the related acoustic landscapes through auralization techniques to increase the opportunities offered by the VR world-specific entertainment and musical sector. [1]

The sector's interest has grown enormously in recent years, also with the effects of the COVID-19 pandemic, which imposes the development of alternative proposals for the use of the Artistic and Cultural Heritage, aim to implement technologies for new commercial horizons to attract new audiences [2]. The acoustic characteristics find increasing place also in the context of documentation and safeguarding of cultural heritage. In 2017 UNESCO, through the document "The importance of sound in today's world: promoting best practices" [3], underlined how the sound of existing or historical places constitutes one of the factors of interest for the protection of the Heritage [4].

The acoustic features of an environment of cultural and patrimonial interest are an immaterial consequence of its construction, from the materials to the furnishing systems that make these spaces usable [5].

Studying the three case studies at the European level made it possible to develop an appropriate methodology dedicated to digitalization and virtual reconstruction. These processes aim to obtain reliable assets to set the subsequent auralization processes and develop multisensory 3D models, reliable and performing both in terms of graphic rendering and virtual use and in terms of acoustics.

Figure 1 – The three case studies of the AURA project and its partnership

2. AIMS AND METHODS

The paper aims to show three different approaches to the issue of morphological/dimensional survey of theater halls, each aimed at creating a 3D model to support the processes of auralization and immersive virtualization.

The methodology started with the dimensional accuracy of digital surveys conducted by TLS instruments for the subsequent 3D modeling processes. Simultaneously, the construction elements present in the various rooms were identified and subdivided semantically and materially. Based on this classification, an investigation was carried out on the values of the acoustic parameters of the respective

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materials present, in order to create a parametric and codified acoustic database to support the subsequent auralization procedures. The latter and all other virtualization operations have been developed by exploiting the multiple potentialities offered by the game-engine software *Unity*. This platform allows, through specific plug-ins, both the interaction between a variety of textured and untextured 3D models to simulate and optimize the *ArchViz* of environments, and their auralization through the setting of music sources and sound materials associated with the values of the acoustic parameters investigated and the respective surfaces of the imported 3D models.

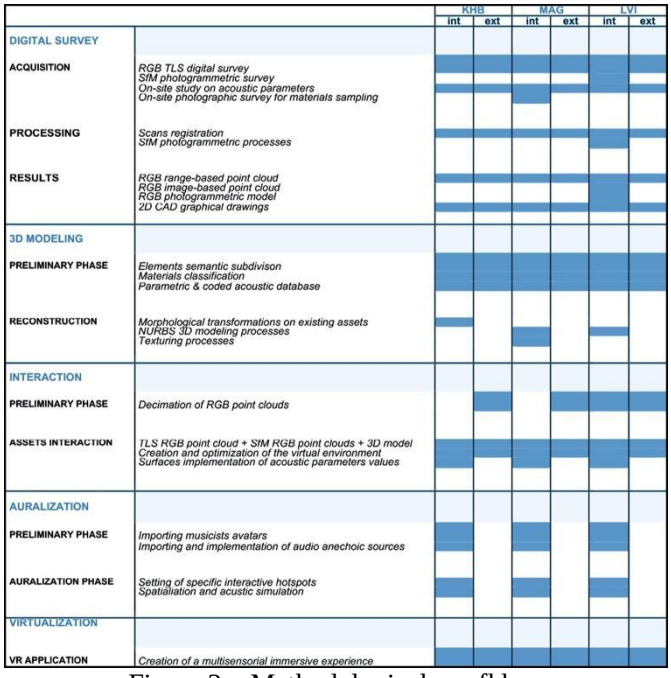

Figure 2 – Methodological worfklow

3. FROM DIGITAL SURVEYS TO 3D MODELING

What follows is a brief summary of the digital survey process to develop the 3D models of the case studies.

3.1 The Konzerthaus in Berlin

The Konzerthaus in Berlin is a neoclassical-style building initially built to a design by the architect Karl Friederich Schinkel, destroyed by bombing during the Second World War and rebuilt and reopened only in 1984 as a concert hall [6].

The documentation activities started in September 2021 with the digital survey of the Gendarmenmarkt square, the foyer, the main hall using a *Z+F 5016* instrument, and the stairwells and side rooms using a *Faro Focus M70*, acquiring a total of about 500 color scans. The research team used the *Leica Cyclone 2020* software to process the large amount of data obtained from the laser-scanner survey campaign and verify the reliability of the alignment of the point clouds. The portion of the three-dimensional point cloud relating to the main room was unified, exported, decimated, and, subsequently, became the metric support for the dimensional adaptation of the 3D model.

3.2 The Lviv Opera House

The second case study is the Opera and Ballet Theater of Lviv (Ukraine). The theater was built in the city center in the late 19th century based on architect Zygmunt Gorgolewski's project. The project provided the burying of the Poltva river for constructing the new complex and thus preparing one of the first examples in Europe of reinforced concrete foundations.

The theater is Neo-Baroque style with an Italian main hall with some Art Nouveau elements and enriched by stuccos, statues, and oil paintings. The main facade is set at the end of a long tree-lined avenue that, over the years, has become the heart of the historic center, now under UNESCO protection [7].

The digital survey required two different temporal tranches. At the beginning of 2021, the first campaign acquired internal geometric data of the room, foyer, and corridors with 160 B/W scans using a laser scanner *Leica C10*, combined with SfM photogrammetric surveys to acquire the colors. At the end of 2021, the second survey campaign provided 160 RGB colored scans of the external areas and the internal environments with a *Faro Focus M70*. The acquired data required the same processing previously described to develop point clouds at different metric and graphic detail levels.

3.3 The Teatro del Maggio Musicale Fiorentino

The third case study is the Teatro del Maggio Musicale Fiorentino, designed by the architect Paolo Desideri of the ABDR studio and opened in December 2011. The building represents one of the most relevant contemporary design interventions in the Florentine architectural scene. Inside there are three large theatrical venues: a recently opened auditorium, an outdoor *cavea*, and the main hall of the opera house, enclosed within a stereometric volume in the shape of an “iron of horse” [8].

The digital survey campaign of the complex was carried out in the first months of 2021, acquiring geometric and chromatic data using two different TLSs, respectively, obtaining a total of 180 colored scans with a *Z+F 5016* and 120 B/W scans with a *Faro Focus M70*. These then underwent the same processing process described above. The global point cloud obtained became in this way the metric basis for the main room's graphic rendering and 3D modeling phases.


Figure 3 – Berlin Konzerthaus’s main hall point cloud

4. FROM 3D MODELING TO VIRTUALIZATION FOR AURALIZATION

The 3D modeling phase of the three case studies is presented following the digital survey activities. The morphological assets on which to set the three main halls' subsequent auralization and virtualization processes were elaborated.

To exemplify this operational workflow common to the three cases, a specific methodological aspect addressed during this research experience is presented below.

4.1 The Konzerthaus in Berlin

As a partner in the AURA project, the Konzerthaus institution made available for this case study a textured 3D model of the main hall previously prepared for another project. However, as a result of specific morphological analyses conducted on the digital survey results, it turned out that this model did not metrically reflect the real dimensional aspects of the environment, making some morphological modifications based on the more reliable point cloud indeed necessary.

The hall model was thus resized through specific morphological transformation operations and referred to the coordinate system set for the global point cloud so that it could be integrated within the environmental context of the square. Next, as we will see for the other cases, a semantic classification of the elements in the main hall was developed. Each surface of these was assigned and coded with a different virtual material in order to facilitate the association of the respective acoustic values necessary for the development of the subsequent auralization processes.

4.2 The Lviv Opera House

The descriptive and geometrically more defined B/W point cloud of the hall was thus exploited to create an untextured NURBS model of the theater environment, which also featured the semantic and textural subdivisions necessary for auralization.

The texture obtained from the room's photogrammetric processes was exploited to associate the color data with these surfaces. The photographs were initially aligned within the *Agisoft Metashape* software, thus obtaining a scattered point cloud that was subsequently densified using specific algorithms and referenced with points homologous to that developed by the TLS survey. Finally, the previously realized model was imported as a mesh, which, sharing both morphology and spatial coordinates with the dense cloud, was mapped using the textures of the photographic data used for photogrammetry.

In this way, for the immersive virtualization project of the main hall, it was possible to experiment with the interaction between two different assets, inserting within the same *Unity* virtual environment - and according to the same coordinates - both the 3D model equipped with separate surfaces that can be associated with the acoustic parameters of each material, and the textured model, which is visually more faithful. The two 3D assets, overlaid with each other and made the former invisible during the VR experience, thus ensuring both the environmental acoustic simulation developed by the auralization of the 3D model and the realistic graphical rendering of the theater complex.

4.3 The Teatro del Maggio Musicale Fiorentino

As with the other case studies, three-dimensional processing was conducted within *Rhinoceros* software, using which, exploiting the potential of NURBS modeling, the 3D model of the main hall and its elements was created, based on 2D elaborates developed from range-based data and, for some complex geometries, directly on portions of the decimated point cloud. As set forth above, the modeling operations were conducted by referring to a semantic and textural subdivision of the architectural components present, categorizing them into typological categories and associating coded virtual materials.

From this point of view, in addition to the modeling of the architectural elements of the hall, the modeling of the acoustic reflector systems, such as *scattering* panels or acoustic curtains, and the furnishing elements, such as seats, whose wide presence (more than 1700) is highly relevant in the acoustic study of the hall, and consequently, in the auralization processes, was considered of great importance.

Finally, before proceeding to the latter and immersive virtualization on *Unity*, photographic campaigns were conducted aimed at sampling the actual materials in the room, for each of which a photorealistic texture was created to map all the surfaces of the 3D model, optimizing their graphical rendering for the *ArchViz*. [9].

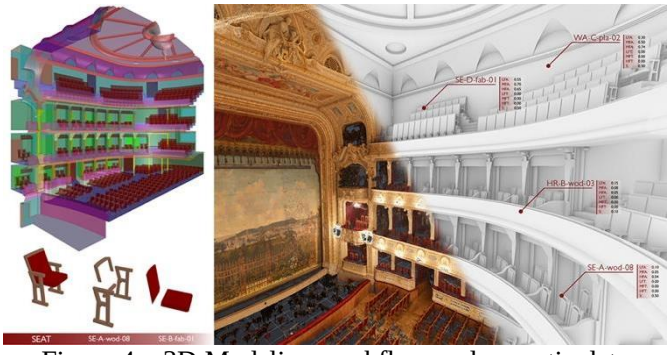

Figure 4 – 3D Modeling workflow and acoustic data enrichment for the Lviv Opera House case study

5. CONCLUSIONS

The solution proposed within the AURA project and presented in this paper for the three case studies of the Berlin Konzerthaus, Lviv Opera House and Teatro del Maggio Musicale in Florence foresees not only to develop multisensory 3D models based on reliable metric-morphological supports but mainly to create a scientific and replicable methodology of the workflow of the elements classification and virtual reconstruction aimed at auralization. The evolution of technologies in the field of investigation and protection of tangible cultural heritage has significantly increased the possibilities as new LIDAR tools and modeling and rendering methodologies combined to

recreate a virtual double of the object investigated preserving and protecting its memory and image.

The project started experimenting with the possibility of collaborating specialists who can interact within virtual workspaces and immersive multimedia systems, starting to investigate the possibilities of using the data produced as valuable tools for dissemination and communication and entertainment. By integrating auralization and a reliable and realistic visual experience based on data acquired through integrated TLS digital survey and Structure from Motion (SfM) photogrammetric techniques, it is possible to investigate the mutual influence that visual and acoustic stimuli have on the perception of the virtual experience. These outputs will allow the user to experience, through Virtual Reality applications, a perceptually multisensory experience, associating an immersive visual representation with an acoustic simulation.

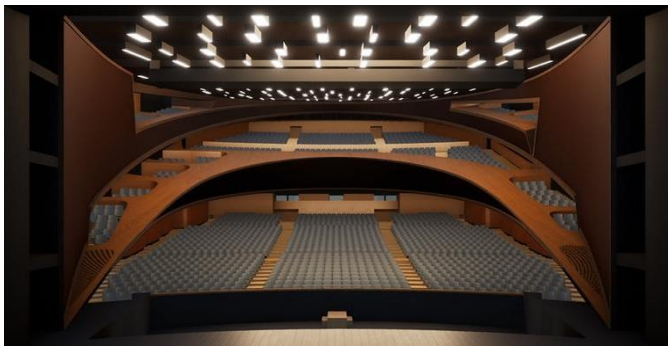

Figure 5 – Virtualization of the Teatro del Maggio Musicale Fiorentino

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Andrea Lumini wrote the paragraphs "2 - Aims and methods" and "4 - From 3D modeling to virtualization for auralisation".

Federico Cioli wrote the paragraph "3 - From digital surveys to 3D modeling".

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Finally, 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.

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