Archeologia e Calcolatori
32.1, 2021, 351-357
doi 10.19282/ac.32.1.2021.19

INTRODUCTION: AN OVERVIEW OF HOW VIRTUAL RECONSTRUCTIONS AND SOUND SIMULATIONS CAN IMPROVE OUR KNOWLEDGE ON ANCIENT MUSICAL INSTRUMENTS AND SOUND HERITAGE

This special issue aims to discuss how digital technologies based on 3D modelling and sound simulation can expand our knowledge of ancient musical instruments and sound heritage. Computational methods for processing the 3D models allow for a more accurate analysis of surfaces, volumes, internal structures, and density of materials of ancient instruments. Being non-invasive, these methods enable the study of the instruments' measurements and morphology, overcoming the limitations posed by their fragility. Although reconstructions cannot tell us unequivocally how ancient musicians played these instruments and how audiences perceived their sounds – given that we cannot replicate the experience of ancient listeners – they offer the chance to not only break through the time barrier by reviving sound emissions, but also to explore the types of sound experiences that ancient peoples were exposed to, taking in consideration that they would be operating within different cultural, social and musical contexts (Betts 2017, 23-25).

Whilst the consequences for our interpretations are still to be defined, the application of technology to the study of instruments allows for different kinds of approaches and studies that aim to acquire a better understanding of ancient sounds, such as those produced by string instruments, but also wind and percussion instruments, including examples from the Greek, Roman, and Etruscan periods as well as ancient instruments found in Northern Europe and South America (De Angeli *et al.* 2018). By combining optical metrology with computational analysis, some of the subjective observations on ancient instruments can be substituted by measurable parameters, opening up new perspectives for the study of ancient music and sound heritage as well as the organological and technological development of instruments in order to understand the artisan production manufacturing process of these special artefacts (Safa *et al.* 2016). Studying how these material objects have undergone transformations and forms of handling, the survey on the evolution of these instruments could help us in defining a novel approach and methodology to the 'active preservation' of instruments and sound tools in order to develop new research fields in both humanities and technological research areas also involving the study of sound heritage (Avanzini *et al.* 2015, 2016; Pretto *et al.* 2020). For this reason, novel methodologies related to virtual reconstructions and sound simulations of instruments and sound heritage are a work in progress (Bressan, Canazza 2013) and are needed to confirm or,

where necessary, modify the hypotheses as well as to enhance and improve new ones (Farina, Tronchin 2013).

Moreover, 3D-printed models can enable the exploration of their musical potential (Both 2008; Bellia 2019a). Indeed, the virtual reconstruction of ancient musical instruments allows us to implement our knowledge of the main processes of their production thanks to the 3D scanning phase (Angela Bellia), the post-processing phase, and the reconstruction phase in a virtual environment (Antonio Rodà, Sergio Canazza, Giovanni De Poli, and Zezhou Sun, Emily Whiting). Digital technologies based on 3D models can overcome further limits related to ancient instruments (Stefan Hagel): given that their reconstruction is virtual, many different hypotheses can be tested despite the fact that these instruments are often damaged and cannot be played anymore (Sun *et al.* 2020). Indeed, it is possible to produce a basis for assessing different reconstructions.

It is worth noting that virtual models can be easily shared, making possible global access to this form of heritage; they can also be printed, thereby providing the opportunity to produce physical copies at a relatively low cost (Zoran 2011; Fangbemi, Zhang 2018; Damodaran *et al.* 2021).

Keeping in mind that virtual instruments can be used in subjective listening tests to compare the 'sound quality' of different instruments for the evaluation of (real or simulated) restoration of ancient instruments, and for preliminary listening tests with newly designed ones before they are actually built, sound features of musical instruments, as well as their vibrational behaviour, represent one of the most important and fascinating fields of acoustics, or even of applied physics (Tronchin 2020). This aspect is sometimes neglected (or at least not investigated enough) during the restoration of ancient masterpieces, even though it is well known that the instruments' sound production is something of inestimable value.

It is worth noting that a significant number of archaeological finds of ancient musical instruments are exhibited at archaeological museums (Georgios Th. Kouroupetroglou, Spyros Polychronopoulos, Konstantinos Bakogiannis). Some scholars are exploring user friendly, adaptable and expandable digital tools in order to create virtual instruments, which can reproduce their sounds within exhibitions (Swift *et al.* 2021) devoted to a lay public and students – and, in some cases, also useful to scholars and researchers – in order to disseminate the knowledge of ancient music not only among specialists, but also to a larger community (Micheloni *et al.* 2016; Bakogiannis *et al.* 2020).

In this regards, it is essential to emphasise that modern studies on ancient music's technical history (Eichmann, Fang, Koch 2012, 2016) should be always seriously considered in order to avoid that digital application might misguide archaeologists and conservators if documented ancient sound – grounded on attested playing techniques and tunings – remains disregarded.

Moreover, in sound simulation of ancient instruments (Terzēs 2020) should be avoid arbitrary sorting into classes, especially if an appropriate modelling description that simulates the basic sound mechanisms and factors is the aim of the reconstruction of instruments.

Digital technologies based on 3D modelling and sound simulation provide new insights in sound studies, as the data can be applied to sound simulators and soundscape reconstructions in ancient architectural structures and ancient spaces (Till 2019). With the aid of new technologies in geo-referenced sound mapping and multimedia applications, it is possible to recreate, play, and test musical instruments and their sounds both under laboratory conditions and on-site in different architectural settings.

In this regard, this special issue aims also to explore the sonic interactions and the spatial configuration of sanctuaries and theatres in their respective landscapes and environment in order to investigate the use of auralisation technology in the archaeological field, as well as experimental interpretative 3D reconstructions integrating acoustic models. Indeed, in the last few years many scholars have devoted their studies and research to these themes with different methods and results, all with the aim of exploring how digital technologies based on 3D modelling and sound simulations can expand our knowledge on sounds and open new perspectives on the study and preservation of sound heritage and audio files (Sergio Canazza, Giovanni De Poli, Alvise Vidolin).

This is an ambitious way of approaching and analysing archaeological sites, and involves speculating on the soundscape of performative spaces of ancient cultures as well as reconstructing how they were experienced. Combining binaural recording technology, psychoacoustic analyses, and site-mapping techniques, research methodology enables researchers to re-create the original conditions with high fidelity along with the precise orientation and directionality of sounds. Since the data points can be generated from digital recordings, this capability can be used to further explore the human sonic experience of the acoustic environment (Jordan 2020; Bellia 2021).

In this regard, it cannot be discounted that the sonic aspects of theatral structures that existed in connection with the origin and significance of their public character might have played an integral and important role in increasing the functionality of these buildings as places of interaction and communication on multiple sensory levels, involving highly visual imagery and dramatic sounds, as well as other sensorial experiences (Cristina Manzetti, Nikos Papadopoulos). Thanks to the analysis of some acoustics parameters and the listening of sounds in a 3D environment, it is possible to explore the creation process of performative structures. Moreover, the study of the sound features and sonic environment of these structures provides us with new insights on their acoustic reasoning and function (Manzetti 2019). In this respect, in recent years the study on sound has attracted enormous interest and yielded

substantial insights, yet there are still many aspects of sound heritage to be explored in order to consider sound as a form of cultural heritage to be understood, preserved and disseminated. For this reason, these topics should be addressed through the contributions of scholars working in various fields, not only including archaeology and archaeomusicology (Both 2009), but also information engineering, interactive museums, sound heritage, acoustics, physics, virtual heritage, ecoacoustics, and craftsmanship.

It should be noted that, although a generation of European researchers has been excluded from the research system of their country of birth due to the stagnating research funding landscape of the past decade and the rigid, conservative, and anachronistic hierarchy of academia in some countries (especially in Southern and Eastern Europe), collaborations and interdisciplinary research involving humanities and technological fields have been enhanced thanks to the hard efforts of researchers and the investment of European resources (Bellia 2019b). Formulating theoretical foundations, principles and processes to be followed (traceable, transparent, reproducible and verifiable), these collaborative and multidisciplinary works can provide not only a better integration and a growing 'ibridation' among humanities with technological fields, but also an unmatched contribution to the workings of innovation in the present and in the future of studies related to music and sound, which can be spread widely among researchers and the general public.

By trying and trying again, we will be able to not only produce significant insights on sound heritage and new lines of research in the fields of digital heritage and of digital approaches to historical acoustemology (Geoffroy-Schwinden 2018), but also present a novel analytical framework that models the acoustics of archaeological spaces. As Marie Skłodowska-Curie said: «Nothing in life is to be feared, it is only to be understood. Now is the time to understand more, so that we may fear less».

Preliminary versions of some of the themes contained in this special issue were presented at the webinar *From the Digitalisation to the Virtual Reconstruction and Sound Simulation of Ancient Musical Instruments* held on February 25th 2021 at the Institute of Heritage Science of the National Research Council of Italy. I would like to thank all the speakers for their interesting papers, as well as everyone who attended and participated in creating a positive environment. Special thanks must go to Costanza Miliani, Director at the Institute of Heritage Science, for encouraging me to organise the event. I am also very grateful to Paolo Romano and Nella Pagano as well as to Danilo Pavone, Silvia Iachello, and Fabio Viscuso for their valuable collaboration and support.

My warmest thanks go to all authors who have contributed and have accepted with enthusiasm the invite to take part in this special issue; they have engaged deeply with the critical issues at the core of this volume: Konstantinos

Bakogiannis, Sergio Canazza, Giovanni De Poli, Stefan Hagel, Georgios Kouroupetroglou, Pamela Jordan, Maria Cristina Manzetti, Antonio Rodà, Nikos Papadopoulos, Alvise Vidolin, Spyros Polychronopoulos. I am also very grateful to the anonymous reviewers for their valuable comments on the various essays. Moreover, I would like to express my gratitude to Lucio De Paolis, Raquel Jaménez Pasalodos, Arnaud Saura-Ziegelmeÿer, Ellen Swift, Chrēstos Terzēs and Lamberto Tronchin for their valuable suggestions. Finally, I must extend my gratitude to Claire Ramtuhul for her assistance as this volume has taken shape.

In addition, I would like to thank to *All'Insegna del Giglio*, the publisher of this volume, the editor-in-chief, Paola Moscati, for accepting the inclusion of this work as a special issue of the open access peer reviewed Journal «Archeologia e Calcolatori». Publication was made possible by the project *Stesichoros* (Project ID: 792058), funded by the European Commission's Marie Skłodowska-Curie Actions Programme, Individual Fellowships.

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