CONFERENCE PROGRAM

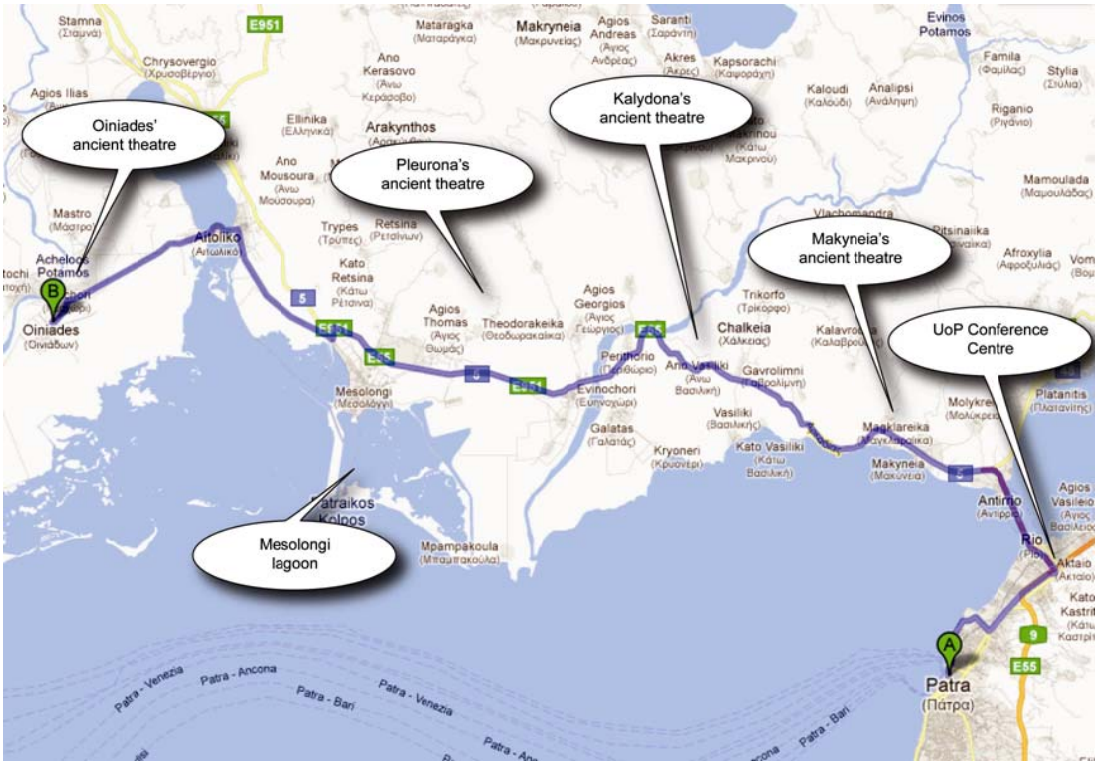
SUNDAY, SEPTEMBER 18th, MORNING

from 9.00 **REGISTRATION**
University of Patras Conference Centre

SUNDAY, SEPTEMBER 18th, MORNING

10.00-16.00 **EXCURSION**
from the University of Patras Conference Centre

Visit the Pleuronas and Oiniades ancient theatres, across the Rio-Antirrio bridge and at approx. 50 Km distance from Patras (see map). The coach will depart from University of Patras Conference Centre at approx. 10.00.



After the visit and prior to returning to Patras, the participants will be hosted by the Municipality of Messologhi town, at a light lunch in the picturesque lagoon.

NOTE: *a coach service will be available to transport participants from the Conference hotels (Achaia Beach Hotel and Tzaki Hotel) and the University Hostel, to and from the Conference venues*

OPENING

SUNDAY, SEPTEMBER 18th, EVENING

19.30 **OPENING CEREMONY - SPEECH**
Old Municipal Hospital garden

Ancient Theatres: Historical and Architectural Development, Spread and Use
Martin Kreeb
archeologist, Assoc. Professor, University of Patras, Patras, Greece

The ancient Greek theatre building materialised without having historical predecessors. In order to perform religious rites, such as the *dithyrambus*, a hymn sung and danced in honour of the god Dionysus, believers needed a specific, architecturally-shaped place to assemble. According to the philosopher Aristotle, *tragedy* developed out of *dithyrambus*. Spectators followed the presentation seated on a gentle slope in an *auditorium* located around an *orchestra*, the area for the spatial arrangement of the performers. As soon as the performances had reached the need of actors, a *stage building*, too, was constructed. These are the three constituents of the ancient theatre, until its end in Late Antiquity.

It is amazing that, once the theatre as architectural form had developed in the beginning of the fifth century BC, nearly every Greek and Roman town felt obliged to erect such a building. Frank Sear, in his study on the ancient theatre as a whole, published in 2006, counts about 700 such theatres. Donors paid for (parts of) these buildings, for the sculptural decoration and so on, those being the emperors and their agents, but also private citizens as benefactors. Theatrical performances depended on sponsors, the so-called *choregoi*, and the theatre served also as a dignified framework for the announcement of honours granted by the people's assembly and given to fellow citizens but also foreign representatives during the festival.

Of course, an architectural form with a life-span of over 900 years was undergoing a certain process of development, which will be described briefly in my lecture. The appearance changed only slightly from East to West, from Asia Minor to Spain, but between the Greek and the Roman type of theatres there were important differences.

Finally, it did not seem reasonable to spend a relatively big amount of money for a building that should be used only once a year, at the god's festival. Therefore, theatres also served as meeting places for people's assemblies, for royal wedding ceremonies, for public banquets paid by town officials in favour of the citizens and foreign sacred envoys, for courts, and for celebrations of the Roman Emperor's cult. The above can give only a first impression of the importance of this architectural form, which primarily served as vehicle for the cultural phenomenon called ancient tragedy and comedy. It is to be welcomed that specialists gathering at the University of Patras will discuss the acoustics in such ancient theatres—noting that no cultural phenomenon would have been possible to exist without the relevant technical substructure.

A reception dinner will follow, hosted by the Municipality of Patras

PAPER SESSIONS

MONDAY, SEPTEMBER 19th MORNING

9.00–9.40 **PAPER SESSION AP1**
Archaeology & Performance
Chair: *Patrizio Fausti, University of Ferrara, Italy*

9.00-9.20 ***Theatre design in ancient times: science or opportunity?***
Alessandro Cocchi
Emeritus Professor, DIENCA Dept. , Engineering Faculty, Bologna University, Italy

An accurate analysis both of the acoustical knowledge in ancient times and of the layout of Greeks and Roman Theatres, jointed with some historical background about people behaviour, seems to put in evidence that in ancient Greek times the design of theatres was based on ideas other than acoustical reasons in the strict sense we give today to the design of a cavea for theatrical performances. In Roman times some important modifications were fitted in the original Greek design, but again the onset of the reverberation seems more a consequence of other targets than a goal to met better acoustical conditions for the audience.
This paper will present some ideas supporting the up mentioned conclusions

9.20 – 9.40 ***Mask, Actor, Theatron and Landscape in classical Greek Theatre****
Thanos Vovolis
Mask, Costume, Set designer, Visiting professor (2007-2010), Dramatic Institute, Stockholm, Sweden

All the theatrical forms developed in Athens during the 6th and 5th centuries BC were forms of masked drama and the mask was an indispensable element in the Ancient Greek theatre. The unique form of the Greek theatre mask which covers the entire head is closely related to its function as an instrument that leads the actor towards a state of mental and vocal expansion—a state of communication with the audience and the theatre space. In this paper I shall examine the connections of the mask to the creation of the chorus and the roles of the Greek drama and the relations of the mask to the text and to the Mythical Topos of the dramatic action. I will also present how the mask becomes a link in a chain of sound and vision that starts with the actor and ends with the theatre space and its surrounding landscape, creating intimacy by acoustics in theatre spaces of great size, all in the service of catharsis.

****invited***

9.40 -10.20 **PAPER SESSION AS1**
Acoustic Measurements & Signal Processing
Chair: *Angelo Farina, University of Parma, Italy*

9.40 – 10.00 ***Acoustic radiation properties of ancient Greek theatre masks***

Alexandros Tsilfidis[1], Thanos Vovolis[2], Eleftheria Georganti[1], Peter Teubner[2], John Mourjopoulos[1]
[1]Audio & Acoustic technology Group, Electrical & Computer Engineering Dept., Univeristy of Patras, Greece, [2]Dramatiska institutet, Stockholm, Sweden

Theatre masks were fundamental elements of the ancient Greek theatre tradition, having a dramatic impact on the artistic performance. Apart from the obvious change of the visual appearance of the actors, the masks also altered the acoustic characteristics of their voices. Therefore, both from the spectator's and the actor's point of view these masks significantly modified the acoustic events and inevitably transformed the overall theatrical experience. As the art of theatre evolved, the physical characteristics of the masks were transformed in terms of their size, mouth and ear openings and construction materials. Quite recently, masks replicating the original shape and structure of the ancient prototypes have been constructed based on the relevant literature and on archeological findings.
In this work, such theatre masks were created in order to measure their acoustic characteristics. For this, the KEMAR manikin was used and the binaural acoustic impulse responses were measured both from the listener's and the speaker's point of view. Measurements are presented in semi-anechoic conditions for various source-receiver distances and azimuth angles and objective measures of the spectral, temporal and timbral characteristics of the reconstructed masks are discussed. In addition, the coupling with real ancient theatre spaces is investigated in order to gain further understanding on the overall acoustic experience. Two of the authors have already analyzed the perceptual effect of the mask on the actors, while studying how they alter the overall artistic performance. In the present work, the above research results will be related to the acoustic measurements, providing insights on the perceptual impact of the masks' employment.

10.00– 10.20 ***Reproduction of Sound Field using a Virtual Loudspeaker Array System***

Tai Chun Fu, Ta-Chung Wang
Department of Aeronautics and Astronautics, National Cheng-Kung University, Taiwan

Traditional sound fields firstly establish a three-dimensional sound field in front of listeners by using two loudspeakers and establish an integrated and multi-level environment by placing several groups of loudspeakers around listeners as time goes by, which assembles the technologies of Dolby Digital or DTS surrounding. However, both Dolby Digital and DTS have requirements on the optimal placement of multi-channel loudspeakers and specific angle between loudspeakers and listeners. Therefore here comes a question that what we can do when the environment isn't available for a specific placement.
This paper aims at solving the placement issue by means of sound field reappearance when an environment isn't available for an optimal placement. Kirchhoff-Helmholtz integration, which has the greatest feature of synthesizing virtual loudspeakers, is employed as the principal tool of wavefront synthesis. Different from previous real loudspeakers that synthesize wave field directly,

PAPER SESSION AS1 *(continued)*
Acoustic Measurements & Signal Processing

virtual loudspeakers can relieve loudspeakers from the restriction of specific placement and can solve the placement issue resulted from unsuitable environment.

MONDAY, SEPTEMBER 19th MORNING

11.00–12.00 **PAPER SESSION AM1**
Analysis & Modeling

Chair: *Penelope Menounou, University of Patras, Greece*

11.00– 11.20 ***Vitruvius and the Acoustics of Ancient Theatre: Analytical and Comparative Study According to Recent Results***

Naif A.Haddad
Department of Conservation Science, Queen Rania Institute of Tourism and Heritage, the Hashemite University, Zarqa 13115, Jordan

One main reason for the success of the ancient theatre concept was its acoustic qualities. The Roman Architect Vitruvius, the chief authority studied by architects, discussed in his Fifth Book on Architecture, *De Architectura*, which appeared between 27 and 23 BC, the construction and proportions of the Greek and Roman theatres. The acoustics of open-air theaters was mentioned by Vitruvius. But he did not mention anything about the acoustics of roofed theaters (Odea). This earliest documentary discussion by Vitruvius shows interestingly his overriding concern is for acoustics, rather than vision, and this even extends to the rules he gives for seating design. However, the acoustic qualities mentioned by Vitruvius in the chapter, have given rise to many speculations and misunderstandings.
This paper will discuss and evaluate the acoustic qualities of the ancient theatres in relation to their design, typology, and architectural formation by testing and evaluation of Vitruvius main issues in the acoustic of ancient theatre and in accordance with recent results of studies and research programs.

11.20– 11.40 ***Echo problems in ancient theatres and a comment to the 'sounding vessels' described by Vitruvius***

Jens Holger Rindel
Odeon A/S, Scion-DTU, Diplomvej 381, DK-2800 Kgs., Lyngby, Denmark

Ancient Greek and Roman theatres are often considered acoustically perfect. However, the semicircular shape of the audience area in theatres built from hard and sound reflective materials may cause acoustic problems, and there is also evidence that the ancient architects were well aware of this. The Roman architect Vitruvius describes in his books on architecture four different kinds of sound reflections in a theatre, one of them called 'circumference' which is an acoustic phenomenon that we today would name a focused echo. Computer simulations of some examples of ancient Greek and Roman theatres confirm that this can be a real problem at some places in the audience area. For this study is used the echo criterion for speech as suggested by Dietsch & Kraak; this is implemented in the

room acoustics software ODEON, and that makes it easy to identify positions with echo problems. A possible solution to these echo problems could be the introduction of sound absorption in the vertical, concave surfaces in a way similar to that described by Vitruvius for the sounding vessels, i.e. in niches between the seats arranged in a horizontal range halfway up. Reading the description by Vitruvius in this light, it makes good sense if the vessels are supposed to act as sound absorbing resonators. Since they are efficient in a narrow frequency band, it also makes sense to apply different sizes with resonance frequencies distributed over two octaves, as described in detail by Vitruvius. Finally, it is noted that the principle of installing the sounding vessels in the theatre comes from older Greek references; obviously Vitruvius had no experience with the vessels himself, but he refers to a scheme based on music theory made by Aristoxenus (4th century BC), who was a famous Greek philosopher and expert in music theory.

11.40– 12.00 ***Acoustic Study of a Roman Theatre in Hispania: Colonia Clunia Sulpicia***

G. Vallejo-Ortega[1], J.I. Sánchez-Rivera[1], M.A. de la Iglesia-Santamaría[2],
[1]Department of Applied Physics, [2]Department of Architectural Theory and Architectural Projects, Architecture School, Valladolid, Spain

This work presents the most excellent conclusions of the acoustic study made in the theatre of Clunia, a Roman city (conventus iuridicus) situated near Coruña del Conde, in the province of Burgos (200 km North from Madrid, Spain). It shows the relation between geometry and the physical parameters that characterize the sound of a room and they have been analyzed by means of simulation.
Clunia Roman Theatre dates from the I Century AC, and currently it is an archaeology ruin in a restoration process. Its dimensions are very significant, with a capacity estimated around 8000-9000 people and 100m diameter on the ground. The theatre responds to a type of enclosures where acoustics constituted for its builders a major challenge. The work is developed in several parts:

- Analysis of the criteria applied in the design of the theatre, that although responded to the classic pattern of these enclosures, it has their peculiarities with respect to the many that were built in the Empire area. For this we shall be guided by the writings bequeathed by the Roman Architect Vitruvius (I Century B.C) in his Fifth Book about Architecture, where he puts in relation geometry with the acoustics of these theatres.
- Presentation of the simulation results by computer using the CATT Acoustic software, which covers, on the one hand, a geometrical analysis of the trajectories of the source-receiver sound rays and, on the other hand, an evaluation of the parameters that define its acoustic quality. The software was used to analyze the acoustics as if it were an enclosed area and not an open area, as the Greek and Roman theatres are, which has been solved in the modelling closing the theatre with a ceiling of maximum absorption. This is based on the concept of maximum absorption (absorption defined as no reflection) of an open surface as a window, where the sound passes through it freely without any portion of the sound energy is reflected back.

12.00–13.00 **PAPER SESSION AR1**

Architecture, Ritual spaces & Roofed theatres

Chair: *Alessandro Cocchi, University of Bologna, Italy (emeritus)*

12.00–12.20 ***Acoustic Behaviour of the Chamber of Dead in the Nekyomanteion of Acheron River***

E. J. Sellountos, Demosthenes K. Polyzos, Stephanos A. Paipetis
Department of Mechanical Engineering & Aeronautics, University of Patras, Patras, Greece

The acoustic behaviour of the Sacred Crypt, an underground structure in the Nekyomanteion of Acheron River, is investigated. A thorough numerical study reveals that advanced knowledge of interior acoustics was employed in the construction, allowing for acoustical effects, making the alleged communication with the dead more impressive.

12.20–12.40 ***Architectural and scenery design implementation for the improvement of the soundscape of ancient theatres***

Kalliopi Chourmouziadou[1], Jian Kang[2]
[1]School of Architecture, Democritus University of Thrace, Xanthi, Greece,
[2]School of Architecture, University of Sheffield, Western Bank, Sheffield, U.K.

The application of contemporary scenery to ancient theatres is necessary for drama performances. Drama, architecture, scenery design and acoustics are closely related in this study. Although scenery was used in antiquity to lead the viewer into the imaginary world the play referred to, today it is more related with the aesthetic aspect of the performance rather than the functional. Previous research has investigated the acoustic effect of scenery, through on-site measurements, computer simulation and scale modeling, indicating basic forms that can improve the acoustic environment of the theatre. However, aiming to the multisensory experience of the performance as, the term 'soundscape' is introduced for ancient theatres, because of the importance of sound perception, the landscape of ancient theatres and the act of drama. Thus soundscape involves both physical measurements but also the cooperation of human and social sciences.

This study introduces scenery design as one of the parameters that can affect the soundscape of ancient theatres and of open-air theatres that were created in the 20th century based on the same principles. Previous categorisation and acoustic analysis of sceneries that have been created for drama performances in open-air theatres is discussed and optimised forms of scenery in terms of acoustics are suggested. Also, architectural details applied to new open-air theatre design can improve its acoustics. Apart from the investigation of the acoustic effect of a basic form of scenery design, this paper introduces acoustic simulation as a tool for creating scenery design, without limiting inspiration. In detail, during the process of design acoustic simulation can indicate the boundaries and the materials that enhance acoustics, for a scenographer to appropriately adjust the scenery. Moreover, it provides guidelines for architects, scenery designers, directors and acousticians.

PAPER SESSION AR1
Architecture, Ritual spaces & Roofed theatres *(continued)*

12.40– 13.00 ***Current Operation of Ancient Greek Theatres: the problem of environmental noise***

Nikos Barkas, *Nikolaos-Georgios Vardaxis*
Department of Architecture, School of Engineering, Democritus University of Thrace, Xanthi, Greece

Distinctive principles of design were applied to ancient Greek theatres in every region and time period, and flexible solutions were found for each theatre's individual problems such as location and architectural composition, statics and drainage, visuals and acoustics, stage equipment and theatre machinery.

The revival of ancient drama (from the early 20th century), the demand to bring performances back to their natural place (about eighty years ago) and the popular trend that has developed since, have given priority to matters of mild and reversible interventions so as to ensure the proper conditions for the operation of theatres. Despite the serious distortions brought about by Roman interventions or lasting destructions, in most cases the reopening of the theatres is deemed feasible. Any disagreements as to the organisation of performances are usually centred on the manner and position in which modern infrastructures are to be installed. However, any attempts at consolidation and restoration prove to be incomplete without the corresponding acoustic interventions, since the contemporary sound environment is a destructive nuisance to outdoor acoustic comfort, while the various stage-design solutions normally fail to exploit the natural (passive) acoustic potential of the theatre space.

The purpose of the paper is to present the current situation of fourteen (14) ancient Greek theatres (Theatre of Dionysus Eleftheреus, Thorikos, Amphiaraion at Oropos, Eretria, Argos, Epidaurus, Megalopolis, Delphoi, Larisa, Dion, Dodoni, Filippoi, Thassos, and Maroneia), the assessment of their contemporary sound environment and the acoustic evaluation for their current or potential reopening. Furthermore, the effect of traffic and other urban noise to the emergence of sound and speech intelligibility will be presented via specific examples.

14.00–15.00 **KEYNOTE SPEECH K1**

presentation via Skype

Chair: *Michael Taroudakis, University of Crete, Greece*

14.00–15.00 ***An Analysis of the Aural Experience of Ancient Spaces***

Barry Blesser
Blesser Associates, USA

There are two major disciplines implicit in the study of acoustic archaeology: (1) measuring the physical acoustics of ancient spaces and (2) speculating on the experience and intentions of those people who used such spaces. It is difficult to combine these two disciplines because they each use very different intellectual paradigms. Modern empirical science and technology is directly applicable to measuring physical properties. In contrast, speculating on the aural experience of such spaces is the domain of sensory anthropology and cultural history. These latter disciplines are weak when there are no historic records or sonic artifacts to provide testimonials about experience. When hypotheses based on data are not feasible, a phenomenological approach can offer plausible insights. Recent research in the cognitive sciences concerning brain plasticity suggests that while ancient people mostly shared the common biology of modern man, their brains adapted to their unique experiences and knowledge. By looking at patterns over the last few centuries where is there is some concrete evidence, we can move towards a reasoned speculation about ancient experiences.

MONDAY, SEPTEMBER 19th AFTERNOON

15.00–16.00 **PAPER SESSION AP2**

Archaeology & Performance

Chair: *Nicola Prodi, University of Ferrara, Italy*

15.00– 15.20 ***Uncanny acoustic effects at Chichen Itza: Intentional design?***

David Lubman
DL Acoustics, 14301 Middletown Lane, Westminster, CA 92683,USA

Recent findings provide insight into ancient uses of sound for mind manipulation at Chichen Itza, Mexico, and suggest that ancient Maya builders were skilled theatrical designers. At the pyramid of Kukulkan, the echo of a handclap is transformed into the chirp of the *resplendent quetzal*, a bird venerated by the Maya since ancient times as the messenger of the gods. The transformation of handclaps into quetzal chirps at equinox ceremonies would support belief in the magical powers of their priests. The chirped echo was once dismissed by archaeologists as an artifact of reconstruction. But mounting evidence is now seen as supportive of intentional design. Chichen Itza's Great Ballcourt is located close to the pyramid of Kukulkan. Findings there also suggest that sound was engineered for mind manipulation. Great Ballcourt sound effects, however, are quite different, suggesting that ancient designers had a broad repertoire of acoustic design tricks. Used skillfully, the ballcourt's whispering gallery can produce mind-bending sound effects supportive of the ancient Maya mythology described in their best-known creation story, the *Popol Vuh*. Ballcourt sound effects include hallucinatory disembodied voices, shouting crowds, the whooping of an invisible bird flying rapidly through the ballcourt, and, with middling success,

PAPER SESSION AP2
Archaeology & Performance *(continued)*

the sounds of growling jaguars and menacing rattlesnakes. Some of these effects seem supernatural even to modern listeners. In addition, the whispering gallery can be used as a public address system.

15.20– 15.40 ***Recreating the Sound of Stonehenge***

Bruno Fazenda, Ian Drumm
Acoustics Research Centre, University of Salford, Salford, M5 4WT, UK

Stonehenge is the largest and most complex ancient stone circle known to mankind. In its original form, the concentric shape of stone rings would have surrounded an individual both visually and aurally. It is an outdoor space and most archaeological evidence suggests it did not have a roof. However, its large, semi-enclosed structure, with many reflecting surfaces, would have reflected and diffracted sound within the space creating an unusual acoustic field for the Neolithic Man. This project has reconstructed the acoustic sound field of Stonehenge based on measurements taken at a full size replica in Maryhill, USA. Acoustic measurements were carried out using modern techniques and the response collected in both mono and B-Format at various source-receiver positions within the space. Brief overview of the acoustic parameters together with a comparison to a recent measurement in the current Stonehenge site is provided.
The auralisation process presented uses a hybrid ambisonic and wave field synthesis (WFS) system. Anechoic recordings were rendered as focussed sources in the WFS system whilst their reverberant B-Format counterpart was rendered using ambisonic technology. Using this technology, the original acoustics of the space have been reconstructed for listeners.
The computational load restrictions and system configuration raise important questions on the subjective requirements for real time auralisations of temporal and directional response. The paper discusses the measurement, acoustic response and rendering of single, focused sources within the space. The use of multiple B-Format impulse responses for various source positions allows embedding of focussed sources within the reverberant field.

15.40– 16.00 ***Meter Matters: Embodied Rhythms at Stage as a Challenge to the Acoustics of Ancient Theatre***

Marcus Mota
Drama Lab(LADI), University of Brasilia, Brazil

As documents of aural events, Ancient Greek Dramas remaining texts present different kinds of organization of sound data (Mota 2009).
Metrical design is one of them. It's indicates play structure, body movements at stage, vocal performances, and instrumental rhythmic guides (Scott 2004, Ley 2007). There were more aural events than speech communication: choreographic activities (steps, clapping hands, body percussion, vocal percussion) and musical instruments accompanying (Scott 1984, Kaimio 1977, Gentili&Lomiento 2008). And

PAPER SESSION AP2
Archaeology & Performance *(continued)*

all of them were replied by the sometimes noisy audience, projecting into the acoustic space of the theatre a shared, collective sound experience (Csapo & Slater 1995,Wilson 2007,Wiles 1997). The aim of this paper is a methodological approach to contextualize performance aspects of greek meter in order to subsidize further proposition of new objects e researches in acoustics of Ancient Theatre. So as to do that I present a metrical analysis of opening anapaests of Aeschylus' *Supplices* and it's choreographic and percussive reconstruction. Tensions between metrical and tonal accents generate aural distinctions that informs choral performances and produces links between beats and bits: sequences of weak and strong syllables manipulates psycoacoustic parameters (Sethares 2007) by accumulation of temporal and loudness modulations. Choral density (physical movements and steps on floor) opens new horizons to perception of sounds in open air spaces.

MONDAY, SEPTEMBER 19th AFTERNOON

16.20- 17.00 **TUTORIAL SESSION T1 (invited)**
Analysis & Modeling

Chair: *Roberto Pompoli, University of Ferrara, Italy*

16.20-17.00 ***The ERATO project and its contribution to our understanding of the acoustics of ancient theatres***

Jens Holger Rindel
Odeon A/S, Scion-DTU, Diplomvej 381, DK-2800 Kgs. Lyngby, Denmark

The ERATO project (2003-2006, Contract Number ICA3-CT-2002-10031), was a three-year research project financed by the European Commission under the Fifth Framework INCO – MED Program. The ancient Greek and Roman theatres are famous for the excellent acoustics. However, it is not generally well known that different kinds of theatres were built, for different purposes and with different acoustical conditions. One of the aims in the ERATO project has been to investigate the acoustics of the open air theatres and compare to the smaller, originally roofed theatres, also called odea (from Greek: Odeion, a hall for song and declamation with music). The method has been to make computer models of the spaces, first as they exist today, and adjust the acoustical data for surface materials by comparison to acoustical measurements from some of the best preserved examples, namely the Aspendos theatre in Turkey and the South theatre in Jerash, Jordan. Next step was to complete the computer models in accordance with archaeological information, to make virtual reconstructions of the spaces. The acoustical simulations have given a lot of interesting information about the acoustical qualities, mainly in the Roman theatres, but the earlier Greek theatre has also been studied in one case (Syracusa in Italy). It is found that the Roman open-air theatres had very high clarity of sound, but the sound strength was quite low. In contrast, the odea had reverberation time like a concert hall, relatively low clarity, and high sound strength. Thus, the acoustical properties reflect the original different purposes of the buildings, the theatre intended mainly for plays (speech) and the Odeon mainly for song and music.

17.00–17.40 **PAPER SESSION AM2**
Analysis & Modeling

Chair: *Tapio Lokki, Aalto University, Finland*

17.00– 17.20 ***Acoustic Performances of Ancient Theatres: Real Ancient versus Virtual Architecture***

Mojtaba Navvab[1] , Fabio Bisegna[2], Gunnar Heilmann[3]
[1] Taubman College of Architecture and Urban Planning, The University of Michigan, USA, [2] Dept. DIAEE, Faculty of Engineering, SAPIENZA University of Rome, Italy,
[3] Gfai Tech GmbH, Rudower Chaussee 30, 12489 Berlin-Adlershof, Germany

There is strong demand from the public for the access to the outdoor archeological sites during daytime and even more during nighttime, both for archeological visits and for the organization of several types of cultural events, ranging from sport shows, to symposia and concerts. Most archeological sites cannot be considered sustainable for their cultural heritage that has not yet been reached. The building officials and historical societies that manage the use and operation of these ancient architecture buildings or theatre have outlined series of guidelines for their use by the public that includes the role of acoustics and lighting techniques in the modern use of these ancient places.
The acoustic properties of ancient performance spaces for Greek and Roman theaters have been studied for accurate reconstruction from possible alternatives of material and design evolution by many investigators . Parametric studies and examination of computer simulation methodology for ancient theatres provides new indexes to examine the contribution of each design components.
Measured and simulated results show that scattering and diffraction from seat and architectural elements, which are important in outdoors theatres impact the sound quality and condition. The specific changes in material characteristic have increased the reverberation and enhanced the sound levels. Computer simulations using a range of boundary absorption and scattering coefficients play a very important role in supporting the choice of the best or almost the more acceptable reconstruction, or sustainable design approach among different possible alternatives being practiced by superintendants and the managers of these historical sites.
This paper presents application of a newly developed technique in beamforming as a close numerical examination to put in evidence the relevant acoustical aspects of ancient theatres basing the study on the comparison of ancient and modern structures. Application of the CAVE or Virtual Reality laboratory provides a well-established tool for this task. Simulations have been carried out to evaluate the acoustics of the orchestra, of the cavea and of the stage, using the theatre of Ancient Ostia and the Rome Coliseum theatre as a reference for ancient theatre, and the Michigan Stadium as a modern architecture theater. The use of Virtual Reality and virtual reconstructions of these theatre combined with auralization techniques provided the opportunities not only to investigate performance of these theatres in different eras but also provide a different experience for the users within the virtual world of ancient acoustics given the growing computer a access and their availability for not only visualization but also virtual acoustics

PAPER SESSION AM2
Analysis & Modeling *(continued)*

17.20– 17.40 ***The Acoustic Evolution of The Large Theatre of Pompeii***

Gino Iannace, Luigi Maffei, Patrizia Trematerra
Built Environment Control Laboratory Ri.A.S., Second University of Naples, 81031, Aversa (Ce), Italy

The city of Pompeii (Italy) was buried by lava from the eruption of the volcano Vesuvio in 79 AD. The Large Theater of Pompeii was brought to light in recent centuries; in origin it could accommodate about 5.000 spectators, now it has been partly rebuilt, and is used for various kinds of show performance. Last year, the cavea, in the past covered with grass, was covered with bricks. This paper reports the acoustic evolution of the Large Theatre of Pompeii. Starting with from a virtual reconstruction of the theatre in origin, the acoustic characteristics were evaluated using architectural acoustic software "Odeon". Subsequently the acoustic characteristics of the theater after reconstruction of the cavea with the bricks are reported.

18.00–19.00 **WORKSHOP W1**
Patras Roman Odeion

In-situ acoustic response measurements in the Roman Odeion

Purpose of the workshop is to familiarize the participants with the alternative methods of measuring the acoustic response of an ancient theatre. Here, the workshop will be concerned with measurements of the Patras's Odeion which is a well-preserved Roman amphitheatre, located within the city of Patras. The theatre was constructed early in the 2nd century AD, having a capacity of 2300 spectators, but became disused after the 3rd century AD. The theater was discovered in 1889 covered by earth and was later restored, used until this day for music and theatrical performances. Special features of the theater is that brick was employed for the construction of the concave structure ("koilon" in ancient Greek or "cavea" in Latin) and its façade (although seating and aisles were covered by marble) and its complex and large brick stage structure ("skene" or "scaena"), typical of Roman theaters, which is still largely preserved today. Some properties of the theater are given in the table below

Radius (m)	Slope (^{0})	Rows	Capacity
23.75	30.8	28	2.300

For the measurement, alternative techniques will be employed based on omnidirectional microphone, binaural dummy head and microphone arrays. Given that the acoustics of the odeion have been also simulated in the computer[1], it is possible to perform the measurements in one or more of the positions employed for the simulations, so that some comparisons between measurements and simulations may be later performed.
It is envisaged that some of the material obtained by these measurements, will be form the examples for the **Tutorial T3.**

[1] *Stamatis Vassilantonopoulos, Panagiotis Hatziantoniou, John Worley, John Mourjopoulos, Juha Merimaa*, "The acoustics of Roman Odeion of Patras: comparing simulations and acoustic measurements", Forum Acusticum 2005, Budapest.

9.00 - 11.00 **PAPER SESSION AM3**
Analysis & Modeling
Chair: *George Cambourakis, University of Athens, Greece*

9.00 - 9.20 ***Validation of a numerical code for edge diffraction by means of acoustical measurements on a scale model of an ancient theatre***

Nicola Prodi, Andrea Farnetani, Roberto Pompoli
Dipartimento di Ingegneria, Università di Ferrara, Ferrara, Italy

An efficient and reliable method to model edge diffraction is required in view of further developing the computer simulation of rooms. Despite the sophisticated numerical approaches already available a parallel experimental validation is needed in order to better understand the merits and efficacy of the edge diffraction modeling. In this work the Svensson-Andersson-Vanderkooy time domain modeling was tested by comparing with a set of experimental measurements taken in a 1:20 scale model of an ancient theatre. In fact the tiers of steps of an ancient theatre consisting of the cavea alone are an ideal benchmark to model edge diffraction. In this type of space the impulse response consists of two geometrical components (direct and floor reflection) and the tail is made up by diffracted sound only. In the work the 1:20 scale model of the Greek theatre in Syracuse was set up to meet these conditions. Although some geometrical limits of the numerical model in the version here employed, it was possible to correlate theoretical and experimental results under few conditions and for a number of seating positions. Within the above limits the edge diffraction modeling provided a reliable impulse response particularly in the lower part of the cavea.

9.20 - 9.40 ***The significance of sound diffraction effects in predicting acoustics in ancient theatres***

Panos Economou[1], Panagiotis Charalampous[1], Stefanos Ioannides[1], Polykarpos Polykarpou[2]
[1] P.E. Mediterranean Acoustics Research and Development, Cyprus
[2] Electrical and Computer Engineering Department, University of Patras, Greece

This paper examines the effect of sound diffraction in predicting sound propagation in ancient theatres. Few simulation studies to date concerning ancient theatre acoustics were conducted with diffraction effects. While sound diffraction effects in ancient theatres are known qualitatively, rarely have they been quantitatively documented. In this paper, the ancient theatre of Kourion in Cyprus was acoustically modeled and simulated, in two commercially available software applications, an application which handles sound diffraction to high orders and an application which does not handle sound diffraction. Sound measurements were also taken at the theatre for comparison purposes. All analyses were conducted in the frequency domain. Comparison of results of the variation of sound pressure level with distance and frequency shows that the contribution of sound diffraction is significant. It is proposed that future acoustical simulations of ancient theatres should include sound diffraction effects.

PAPER SESSION AM3
Analysis & Modeling *(continued)*

9.40 – 10.00 ***On the acoustics of the gallo-roman theater of Sanxay (France)***

Jacky Tartarin
"Pôle Poitevin de Recherche pour l'Ingénieur en Mécanique, Matériaux et Energétique" CNRS Institute (University of Poitiers, France)
Ecole Nationale Supérieure d'Ingénieurs de Poitiers, Bât. 17, 86022 Poitiers Cedex, France

The gallo-roman theater of Sanxay is staying against a natural 13 meters high hill, on the right bank side of a small river (the Vonne) near Poitiers (France). In fact, it is a sort of "half-amphitheater". It is characterized by an unusually circular and large *orchestra* (30 meters diameter), by the *vomitoria* which are parallel of a narrow *scænæ*, without any *frons scænæ*. The *cavea* (90 meters maximum diameter) is divided in three different *mænania* and could receive more than 6500 spectators on wood steps. Nowadays, large ruins of rough stones edge the *vomitoria* (till two meters high) and are outcropping on the *cavea*. The shape and the slope (about 25° angle) allow good sight from all positions.
Since ten years, there is an important opera festival held here in August (http://operasanxay.fr, with some photos of the site). The "acoustical qualities" are subjectively well appreciated by the musicians and the audience.
Answering the request of the organizing committee, we investigate different acoustical criteria (RT, EDT, Clarity80, Definition50, STI, RASTI, IACC, sound strength Gmid) by means of in situ experimental measurements (based on MLS methods) and compare with greek and roman theaters studied, for example, in ERATO program. Although the amphitheater is mostly covered of grass, we find almost same magnitude criteria and similar general trends.
Some other investigations (computer simulations with *CATT Acoustics*, measurements with a dummy head) are in progress (to be presented in Patras). As well, these results would be useful in case of future planned restoration.

10.00– 10.20 ***Acoustic simulation of the Ancient Theatre of Kourion in Cyprus***

Polykarpos Polykarpou, Stamatis Vassilantonopoulos†, John Mourjopoulos
Electrical and Computer Engineering Department, University of Patras, Greece

This study examines the acoustic simulation of the Ancient theatre of Kourion, located in Cyprus. This theatre was first build in the 2nd century B.C., during the Hellenistic era and later it took the form of a Roman theatre. The theatre is well preserved today and still used for theatrical and music performances. The simulation aims to calculate the acoustic parameters and speech intelligibility which help to define the acoustic behavior of the theatre. In addition to this, an auralization of the theatre was created, giving an impression of how the music, or the speech, would sound if replayed in the Ancient theatre of Kourion.
Firstly the model of the theatre was created in AutoCAD software, after measuring the surfaces of the theatre as it stands today. A two dimensional plan of the theater, indicating the theatre's form in antiquity, was very helpful for the design of the part of the theatre that wasn't reconstructed. In subsequent, the Ancient theatre was modeled in commercially available acoustic software.

PAPER SESSION AM3
Analysis & Modeling *(continued)*

The simulation was performed for four different cases. The parameters which were changed, in each simulation, are the position of the source and the presence or not of an audience. Each simulation differs only in one parameter compared to the other simulations. The findings are presented in color maps of the audience area, but they are also given with numbers in arrays located in the annex of this thesis. According to these results, the Ancient theatre of Kourion has a very good acoustic performance. Additional, utilizing the findings of this study, a compare was made, to the findings of the acoustic simulation of the Ancient theatre of Epidaurus. The results of this comparison are very interesting, since they indicate quite resemblances of the acoustic performance of the two Ancient theatres.

10.20– 10.40 ***Cross laminated timber absorbent***

Jan Arne Austnes[1], Kristine Nore[2], Jarle Aarstad[2]
[1]Sweco Norway AS, [2]Norsk Treteknisk Institutt, Norway

Wall and ceiling systems fabricated as cross laminated timber (CLT) is gaining popularity in Europe. When designing a sports arena or a multipurpose hall you look for just such a light weight building element with appropriate load bearing and aesthetic qualities. These easy adaptive elements also liberate the designer in building future green buildings. The use of traditional acoustic panelling might be inconsistent with the wish to expose wooden building parts and since modern architecture prefer clean surfaces and tidy interiors, limitations will be set on natural acoustic damping. Inherent acoustic damping of the element has evolved as a design challenge.

This paper presents a solution on refining a standard CLT element to become a Helmholtz resonator, primarily to reduce the room reverberation time at the lower frequencies. From ancient times – long before Helmholtz - the volume resonators is known. The existence of natural slits between boards of the fabricated element sat us on the path. If these slits could be connected to an appropriate volume, the basic parts of a volume resonator were at hand.

This volume was furnished by removing every second centre cross-board of the CLT element, and the slits were widened by cutting open slits through the surface boarding. Mineral wool volume infill made the last component of the resonator.

The paper includes the theoretical considerations of the resonator design, the acoustic laboratory full scale measurement results and a reverberation time test of a newly built library hall with the actual CLT elements installed as exposed load bearing ceiling and walls. The most cost effective use of CLT has so far proven to be load bearing floors and roof constructions with a ceiling as an exposed CLT element. The laboratory results are used to evaluate the effect of integrated acoustic damping and to define the need for future development work.

PAPER SESSION AM3
Analysis & Modeling *(continued)*

10.40– 11.00 ***Computer simulation of the effect of the audience on the acoustics of the Roman Theatre of Beneventum (Italy)***

Gino Iannace, Luigi Maffei, Francesco Aletta
Built Environment Control Laboratory Ri.A.S., Second University of Naples, 81031, Aversa (Ce), Italy

The acoustics of the Ancient Theatre of Beneventum has been given attention by the authors since five years ago when measurements were carried out in the aim of its characterization in the present state. This theatre was built by Emperor Hadrian in the 1st century A.D. Later, historical events like barbarian invasions, earthquakes and floods determined its abandonment. A large part of the materials of the construction was used to build defensive walls in the Lombard period and for the embellishment of churches and palaces. During the course of subsequent centuries the theatre became the settlement of humble dwellings. At the start of the 20th century the crumbling houses were demolished to start the reconstruction of the theatre which was completed, as it appears in the present state, in 1950.
This paper reports a computer simulation of the acoustics of the Roman Theatre performed with the aid of the software Odeon. Calculated results are compared with those stemmed from the previous measurements carried out by the authors in the unoccupied theatre. Furthermore, a simulation of the effects of audience occupation on the acoustics is presented.

TUESDAY, SEPTEMBER 20th, MORNING

11.20–12.00 **TUTORIAL SESSION T2 (invited)**
Analysis & Modeling

Chair: *Nikos Barkas, University of Thrace, Greece*

11.20–12.00 ***The acoustics of antique theatres: Canac's life work revisited***

Jean-Dominique Polack
Professor, LAM/IJLRA, Université Pierre et Marie Curie/CNRS UMR7190/ministère de la culture et de la communication, Paris, France

In 1967 François Canac published the results of more than 20 years of investigation on the ancient theatres. What he was after was an understanding of the outstanding acoustical qualities of those theatres, which he summed up in two sentences: they can host many spectators, up to 12000 in Syracuse; one hears well from all seats.
This outstanding piece of scientific research is however little known in the English speaking word. Our goal is therefore to report on the main finding of Canac's, the importance of reflecting surfaces, which he converted into a canonical equation of the antique theatre. We will also report on the techniques Canac used to derive this equation, and conclude, as did Canac in his time, with the acoustical teachings from Antiquity that are still actual.

12.00–13.20 **PAPER SESSION AR1**
Architecture, Ritual spaces & Roofed theatres
Chair: *David Lubman, DL Acoustics, USA*

12.00– 12.20 ***Perceptual validation in the acoustic modelling and auralization of heritage sites: The Acoustic Measurement and Modelling of St Margaret's Church, York, UK***

Aglaia Foteinou, Damian T. Murphy,
Audio Lab, Department of Electronics, University of York, York, UK

Through the use of 3D computer simulations and auralization, it is now possible to reconstruct historical monuments in a virtual environment and reveal further visual and acoustical information about the past. In previous studies, models are usually based on available evidence, often in combination with data obtained from sites and in-situ measurements in their current state. Results and validations are then based on objective acoustical parameters, which seem encouraging, however, there is still limited data available in terms of the correlation of these results with subjective evaluation of the final auralization.
This project aims to evaluate perceptual results obtained from the auralization of a heritage site and the correlation with objective acoustical parameters. This will be done by making changes in the acoustical characteristics of the space being studied, which is in this case the medieval St. Margaret's Church in York, UK, which after renovations, is now used for music performances and conferences. The particular advantage being that the church's physical acoustical characteristics can be easily changed through variable acoustical panels and drapes arranged throughout the space, depending on the acoustic requirements of the activity within venue.
Through computer modelling and in-situ multi-source/receiver RIR capture, objective/subjective evaluation has been carried out. The computer model, based on geometric acoustic principles, has been initially optimised according to the acoustical configurations used during the actual measurements. Through comparative listening tests the audibility of these changes for both in-situ and model based measurements has been evaluated, with participants also asked to express the resulting degree of perceived differentiation in each case across both actual and virtual space.
This paper reports on the measurement and modelling work, together with initial subjective testing. Further work will lead to conclusions and recommendations being made for the modelling and perceptual validation of virtual reconstructions of heritage sites, particularly in cases when actual physical validation is no longer possible.

12.20– 12.40 ***The Roman odeion of Nicopolis: Observations of architectural elements affecting its acoustics. Measurements & calculations of acoustic indices***

Goussios Christos[1], Tsinikas Nikolaos[2], Chourmouziadou Kalliopi[3], Kalliris Georgios[4]
[1]Dept. of Film Studies, [2]Dept of Architecture, [4] Dept of Journalism & Mass Communication, Aristotle University of Thessaloniki, Thessaloniki, [3] Department of Architecture, Democritus University of Thrace, Xanthi, Greece

This paper investigates the acoustics of the ancient odeion of Nicopolis for the first time. The odeion is examined regarding its architectural characteristics and their effect on acoustics, for hosting musical events in antiquity, and compared with

other recently studied ancient Greek and Roman odeia & theatres in Greece. The investigation of these buildings and their comparison is multidisciplinary, based on their history, architecture and acoustics. RT60, C80, D50, EDT are some of the acoustic indices studied thoroughly, in order to define the behavior of sound in both the contemporary open-air and the original roofed conditions of the odeion.

12.40–13.00 ***Analysis of the acoustic parameters of the Basilica "Santa Maria" on the performance of the medieval liturgical masterpiece "El Misteri"***
Ramon Peral Orts, Nuria Campillo Davo, Alberto Cervero Casillas
Miguel Hernandez University, Elche, Spain

Our research is focused on the famous liturgical representation that takes place at the ancient Basilica "Santa Maria" located in the Spanish city of Elche. That representation known as "El Misteri" is more than five centuries old, and many years ago became singular for being the only representation performed at a religious stage in the world. Due to this, UNESCO declared it one of the Masterpieces of the Oral and Intangible Heritage of Humanity in 2001. The play has a religious character and shows historical situations of the Bible. It's performed only by males and the female characters are played by children. That's an important detail of the project so we study the acoustical differences caused by the voices.
Our project is based on the research of the room acoustics of that ancient stage applied to the performance of the liturgical piece. Furthermore we will study how the acoustic problems were solved in the Middle Ages. During the play there are many points of sound emitters, as the stage has two levels: the horizontal "terrestrial" stage and the vertical "celestial" stage, characteristic of the medieval mystery play. Actors sing and play instruments from hanging equipment in the air, so the Basilica will be studied as a 3D Stage. Experimental tests have been developed and modeling software will be used to validate the acoustical parameters like Reverb Times (EDT) and represent the behavior of the building. The software simulation will help us to make auralizations, simulating the effect of different sounds in different emitter points. In this manner we distinguish the Basilica and the stages (parts of the play with different sound point emitters). After studying the character of the play (kind of voices, their positions, instruments used, etc.) now we can apply the parameters to the model and obtain the simulation results.

13.00– 13.20 ***The acoustics of the Teatro Ideale by Francesco Milizia (1773)***
Lamberto Tronchin
DIENCA – CIARM, University of Bologna, Italy

During the 18th Century a new idea of theatre architecture was proposed by several French scientists before Pierre Patte. This new idea was based on a democratic vision of the theatre which was founded on the neoclassic architecture. The French vision of the theatre architecture recalled the

PAPER SESSION AR1
Architecture, Ritual spaces & Roofed theatres *(continued)*

Teatro Olimpico in Vicenza, designed by Andrea Palladio, and reintroduced many neoclassical elements like columns, semicircular shape and large balcony instead of boxes.
The new French ideas about theatre architecture did not find many followers in Italy. The only scientists that accepted this new concept of a "democratic theatre" were the architects Earl Enea Arnaldi (Vicenza, 1716-1794) with wrote his "*Idea di un teatro nelle principali sue parti simile a' teatri antichi all'uso moderno accomodato del conte Enea Arnaldi*" (Vicenza, 1762) and Francesco Milizia (Oria, 1725-1798) who wrote the "*Del Teatro*" (Venice, 1773).
Milizia wrote his book after having read the Arnaldi's work and followed the idea of a semicircular plan of the theatre with columns and other elements. He was therefore influenced by the Teatro Olimpico architecture in Vicenza, and introduced many neoclassical elements in his idea of theatre architecture. He proposed the *Teatro Ideale* that would solve several problems existing in the modern theatre architecture, including acoustic difficulties.
In this paper, the *Teatro Ideale* proposed by Francesco Milizia is acoustically analysed. Starting from the sketches that were provided by Milizia, a numerical model was realized and utilized for simulating the acoustic behavior of the theatre, in the same way as today a new proposed modern theatre is acoustically analysed. The results from the simulation are presented and commented, compared with the acoustic data measured in Teatro Olimpico, and rendered by means of 3D auralisation.

TUESDAY, SEPTEMBER 20th, AFTERNOON

14.20–15.20 **KEYNOTE SPEECH K2**

Chair: *Jean-Dominique Polack, University Pierre and Marie Curie, France*

14.20–15.20 ***Cognitive aspects of listening in performance spaces***
Jens Blauert
Emeritus Professor, IKA, Ruhr-University Bochum**,** Germany

The so-called "quality of the acoustics" is an important determinant of how we are listening in performance spaces. Although the term of often used both in science and in practice, it is often not well defined. A closer look shows, however, that the quality of the acoustics is a complex and multi-layered phenomenon. When analyzing or modeling the formation process of the quality of the acoustics, a variety of quality elements and quality features have to be taken into account, whereby the actual relevance and salience of each of them is situation and user specific.
In this lecture we present the architecture of a general conceptual model of the quality-formation process and identify an adequate system of classes of references involved, thereby considering aspects of psychoacoustics, sensory psychology, physics, and the information sciences. Effort will be put into an attempt of discussing the different aspects of sound quality in a unified way,

KEYNOTE SPEECH K2 *(continued)*

such that the general concept of acoustics quality does not change due to a specific application or a specific listener. Rather, it is only the frame of reference that has to be adapted specifically to a particular application. Some frequent problems regarding the identification and specification of proper references are discussed in detail.
The issue of objectivity will be considered in this context. The discussion of the model will reveal its cross-cultural, universal validity, making it a proper conceptual framework for ordering and analyzing the elements of the quality of the acoustics in a broad range of performance spaces from the ancient ages up to modern times.

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TUESDAY, SEPTEMBER 20th, AFTERNOON

15.20–16.20 **PAPER SESSION AP3**
Archaeology & Performance
Chair: *Kalliopi Chourmouziadou, University of Thrace, Greece*

15.20– 15.40 ***An approach into the acoustic evolution of ancient Odea***
Georgios Karadedos, Panagiotis Karampatzakis, Vasilios Zafranas
School of Architecture, Faculty of Engineering, Aristotle University of Thessaloniki , Thessaloniki, Greece

Ancient Roman Odea, in contrast to ancient Greek ones which were used exclusively for musical events, were roofed buildings used for multiple purposes such as theatrical performances, singing exercises, musical shows and poetry competitions among others and they were designed to be in use all year long, in all weather conditions. They were the closed theaters of the Roman elite which from some point in time onwards could not be contempt with just having privileged seats in the open public theaters.
The evolution of the typology of the Odeon is in close relation to the evolution of the large halls of archaic and classical years (such as Telesterion and Bouleuterion), in which there was a permanent trend to move the central pillars to the edges as these were seen as optical and auditory obstructions to the function of the room.
This paper examines the variations that have taken place with the evolution of the typology of the odea in the typology (geometry) and the materials of the constructions using mathematical models and sound prediction software analysis.

15.40– 16.00 ***Ancient Drama: A theater or an opera?***
Kostas Moschos
Institute for Research on Music & Acoustics, Athens, Greece

We have all the experienced of contemporary performances of ancient theater plays. Most of them are based on the concept that the bigger part is performed as prose narration and some parts (mainly the chorals) are performed vocally as songs. Actually the reality in the past time was completely different. The theater

PAPER SESSION AP3
Archaeology & Performance *(continued)*

performances in ancient Greek era were not theater-plays as we know them today but mainly a music-theater were the melodic part was dominating on the play. This forgotten fact was well known to the Italian society of the 16th century, were the try of the revival of the ancient Greek drama led to the birth of western opera.
The famous theater writers of the antiquity were well known composers. We have many testimonies for this. Frynchos on the golden era of tragedy was described as enjoying his audience "using always his sweet melodies". We know also that Sophocles was a very good musician, singer, guitar player and composer. Euripides was also composer of very beautiful "arias" and Aristophanes was mocking him on "Acharneis" that his brain was outside collecting melodies while he was inside the house writing the lyrics. Dionysus of Halicarnassus is describing a song of Euripides that Electra sings on "Orestis" tragedy. In this description he is analyzing how Euripides is connecting the lyrics to melody. The knowledge that the ancient drama was performed as music theater has major importance and has consequences not only on the artistic aspect but also on the acoustics. The singing voice, has a significantly higher intensity than the speaking voice. During the presentation, evidences will be presented supporting all this approach.

16.00– 16.20 ***Proposals for the improvement of acoustics of ancient theaters***
Kostas Moschos[1], Gottfried Schubert [1,2]
[1]Institute for Research on Music & Acoustics, [2] acoustic consultant, Athens, Greece

The acoustics of ancient theaters were, most probably, of very high level. This remark is based not on legends or theories, but on their ability and efficiency in serving the ancient theatre play. We can assume that in spaces of more than 5.000 seats, the acoustic was able to support the performance of theater plays or of music games in order to satisfy the spectators, something that in our time seems to be possible only with the help of electro-acoustic support.
Why has this acoustic ability disappeared? Most probably the ruination of big parts of the scene buildings and the deterioration of the existing surfaces is a strong reason for the lost of this legendary acoustic. What are the solutions today if we want to reuse these open spaces for cultural performances? A usual solution is the application of power amplification. This allows hearing but the sound quality is insufficient. The coincidence between the sound source location and the optical image is completely destroyed. The audience hears the loudspeaker and not the actors as sound sources.
On the Institute for Research on Music & Acoustics (IEMA) we tried to resolve this problem in different ways: a) mechanically, by constructing and using special designed sound reflectors and b) by developing a complex digital stereoscopic audio system with non-apprehensible amplification. These systems were applied experimentally several times on real performances at the Athens Herodium Theater with very satisfactory results. During the conference we will present the idea, the design and the application outcome of these proposals, which can serve as a permanent solution for open space performances.

16.40–17.20 **TUTORIAL SESSION T3 (invited)**
Analysis & Modeling
Chair: *Dimitris Skarlatos, University of Patras, Greece*

New measurement technique for 3D sound characterization in theatres
Angelo Farina[1] , Lamberto Tronchin[2]
[1] University of Parma, Parma, [2] University of Bologna, Bologna, Italy

The definition and measurement of 3D properties of the sound field have been strongly improved in last years, as nowadays spatial properties of sound propagation are considered quite important during design of theatres and auditorium. Besides, a proper assessment of the degree of spatial accuracy is requested during sound reproduction inside 3D listening rooms, initially designed for acoustical virtual reality, but nowadays being employed also in the entertainment industry (Immsound, Auro-3D, NHK 22.2).
Normally, only monoaural or binaural measurements are performed, by means of omni-directional microphones and dummy heads, even though international standards like ISO 3382/1:2009 require measuring some spatial parameters (i.e. IACC, LE, LF): the last two parameters require to be measured with a pressure-velocity (p-v) microphone, but still it is a 2-channels measurement only. 3D impulse responses are rarely measured and employed for sound reproduction. In this paper, an innovative procedure for measuring and analyzing the complete spatial sound information is presented. The description of this new technique is emphasized. Furthermore, the results of a wide campaign of measurements of spatial parameters among different rooms, including some ancient theatres, conducted with the novel methodology, are compared with the results of standard binaural and p-v measurements. The possibility to capture the complete spatial information in real spaces and the significance of 3D spatial parameters is then considered and presented in different cases.

TUESDAY, SEPTEMBER 20th, AFTERNOON

17.20–19.20 **SPECIAL SESSION S1 (invited)**
Acoustic potteries in ancient buildings
Chair: *Jean-Christophe Valiere, University of Poitiers, France*

17.20– 17.40 ***On the relation between Vitruve vasis and medieval acoustic potteries: Literary analysis of ancient texts and comparison with recent observations in situ***
J.-Ch. Valière[1], B. Bertholon-Palazzo[1], J.-D. Polack[2], P. Carvalho
[1]Université de Poitiers, [2]Université Pierre et Marie Curie/CNRS, France

During the last decade, the acoustic potteries inserted into the walls and roofs of medieval and modern churches became again the focus of scientific curiosity after a long time of relative silence. Traditionally, authors from middle age to present time, considered that Vitruve[1] has established the relation between the "vasa aerea" (bronze vessels)[2] in ancient Greek theater and the "fictilibus doliis" (earthen vessels). Actually, based on Aristoxene's theory, the physical explanation of "vasa aerea" given by Vitruve is related to structural acoustics because he stated " … *the voice which issues from the scene, expanding as from a centre, and striking against the cavity of each vase, will sound with increased clearness and harmony* …". Later in chapter 5, he compared them to potteries inserted in walls which cannot have

SPECIAL SESSION S1
Acoustic potteries in ancient buildings *(continued)*

any vibration but only acoustic amplifications or absorptions as Helmholtz resonators. Earlier, authors as Mersenne[3] stated that Vitruve misunderstood the Aristoxene's theory and was very doubtful about the Vitruve's explanation of the "vasa aerea" that he compared to bells.
Considering the recent research of C. Saliou[4], Vitruve had a "romantic" view of the ancient Greek civilization and had a bad opinion of his own period of life (Roman Empire) in terms of architecture. "The ten books of Architecture" is a work to the glory of ancient Greek architecture and he encouraged Roman builders to copy them. Until today, the problem of "aerum vasis" as described by Vitruve in ancient Greek theater is still an open question for specialists. In our opinion, the testimony of Vitruve is mainly an evidence that potteries inserted in walls were already used at the first century before J.C., as he said in the final sentence: "*Many clever architects* who have built theatres in small cities, from the want of other, have made use of earthen vessels, yielding the proper tones, and have introduced *them with considerable advantage".* In the presentation, we will analyze the Vitruve's in relation with his philosophy with regards to acoustics. Then, an analysis of medieval, modern and contemporary texts speaking about acoustic potteries will be achieved in relation with the Vitruve recommendations. At the end, the conclusion of the text analysis will be compared with recent measurements and observations of acoustic potteries which still remain in churches.

[1] Vitruve, Ten books of Architecture, Book 5, chapter 5, De thetri vasis …
[2] Translation in English internet, university of Chicago …
[3] M. Mersenne, Harmonie Universelle, *de l'utilité de l'Harmonie*, p. 34
[4] C. Saliou, La Norme Vitruvienne

17.40– 18.00 ***A study on Aristoxenus acoustic urns (The Vitruvian secret)***

Panagiotis Karampatzakis[1], Vasilios Zafranas[1], Spyros Polychronopoulos[2], Georgios Karadedos[1]
[1]School of Architecture, Faculty of Engineering, Aristotle University of Thessaloniki, Thessaloniki, [2]Department of Mechanical Engineering and Aeronautics, University of Patras, Patras, Greece

In chapters 4 and 5 of his 5th book titled "De Architectura", Vitruvious analytically describes the practice of enhancing and enlivening the acoustics of Greek and Roman stone theaters using bronze resonating urns. These urns were based on the theories of the ancient Greek musician and philosopher Aristoxenos, whose theories are summarized and expanded upon in the same two chapters.
In spite of the above mentioned reliable archaeological source, and the fact that in at least several ancient Roman and Greek theaters special niches have been found that seem to match exactly with the niches described by Vitruvious for the placement of his bronze urns, no such urns have ever been found or excavated up to date. On the same note, many scientists (acousticians) of our age, having examined Aristoxenos theory as described by Vitruvious and experimented with various urns and the Helmoltz effect that these produce, have come to the conclusion that the effect described, while being measurable, is barely audible at a

SPECIAL SESSION S1
Acoustic potteries in ancient buildings *(continued)*

small distance and definitely inadequate to produce the results described by Vitruvious.
All the above, has led most scientists to believe that the above mentioned chapters may not be exactly true in their descriptions, have many omissions and maybe mistakes or are just describing something that was only in Vitruvious mind.
In this paper the whole matter known in the circles of archaeoacoustics as "the Vitruvian secret" is reexamined, from both a theoretical and a practical (experimental) perspective, using modern tools offered us by acoustic science, and by highlighting certain details about the matter we are led to the conclusion that not only was Vitruvious absolutely correct in his assertions, but once the correct understanding of the phenomenon exists, it is easily repeatable in an experiment both diffuse and open spaces.

18.00– 18.20 ***The use of resonators in ancient Greek Theatres***

Spyros Polychronopoulos[1], Dimitris Kougias[1], Polykarpos Polykarpou[2], Dimitris Skarlatos[1],
[1]Mechanical and Aeronautical Engineering Department, University of Patras
[2]Electrical & Computer Engineering Department, University of Patras, Patras, Greece

Vitruvius in "Architectura" describes the use of bronze vases in ancient Greek theaters to improve the acoustic quality of them. The effect of them on the acoustic quality of the theaters is still in doubt. Onorio Belli (1580) refers that in the theater of Lyttus in Crete there were three rows, each with 13 chambers of such acoustic vases. Based on the detailed description of Onorio Belli, an acoustic simulation based on physical modeling of the theater of Lyttus was established. Following the instructions of Frencesco di Martino, and Floriot the acoustic vases, which actually act as resonators placed in cavities under the audience seats, was inserted into the model. The response of the model with and without resonators was used to study the effect of them on the overall performance of the theatre. The detailed effect of the seat shape for the audience was also studied.

18.20– 18.40 ***Acoustic potteries in southern Albania***

Jean-Dominique Polack
Professor, LAM/IJLRA, Université Pierre et Marie Curie/CNRS UMR7190/ministère de la culture et de la communication, Paris, France

In the summer 2007, we had the opportunity to participate to an archaeological campaign in the village of Voskopojë, near Korçë, in the South of Albania. Located on the merchant trail that linked Venice, Dürres and Constantinople in the XVIIth et XVIIIth century, Voskopojë was then a Christian stronghold in a Moslem environment, and one of the most flourishing cities of the Balkans, with 26 orthodox churches, an academy and the first printing house of the Balkans. Our study mainly concerns the St-Elias church from 1751, with some more ancient parts. Its specificity is a wooden ceiling, unique for church this area.

SPECIAL SESSION S1
Acoustic potteries in ancient buildings *(continued)*

Notwithstanding, 33 acoustic potteries are arranged all around the church, most of them just below the ceiling. We will relate our attempt to measure these potteries, as well as the acoustics of the church. We will gives some more example of acoustic potteries from the 4 surviving neighbouring churches, as well as from a mosque and a Koranic school in Berat, the nearest city west of Voskopojë on the ancient trail.

18.40– 19.00 ***Contribution of the knowledge of the acoustic pottery in medieval and modern churches. Statistical studies of about twenty five French edifices***

Jean-Christophe Valiere[1], Benedicte Palazzo-Bertholon[2]
[1]Institut Pprime, CNRS-UPR 3346, Université de Poitiers, 6 rue Marcel Doré, Poitiers, [2]CESCM-UMR 6223, CNRS, Université de Poitiers, rue de la Chaine, Poitiers, France

Within more than one and half century (1830-1990) the problem of acoustic potteries has been mainly addressed by archaeologists. As our knowledge, only R. Floriot [1], in France, achieved an acoustical study, followed by J.M. Fontaine [2], fifteen years later. These two last decades, the subject knew a renewal of interest especially in Europe [3-7] even through a multidisciplinary approach [8,9]. A large part of these recent studies will be edited very soon (in French), in the special issue of the "*Bulletin Monumental*" next October. Nevertheless all these works, the "mystery" of the acoustic potteries raises numerous problems. There is no more doubt on the intention of church builders, thanks to the recent discovery of several old texts. This proves that the way to improve acoustics remains obscure, even though some experiments have been conducted *in situ,* giving different results. In the first case, a noticeable amplification occurs [2] and in the second, nothing clearly appears [2,4]. In the third case, an attenuation of the reverberation seems however perceptible [4].

In the present paper, a statistical study of about twenty five French edifices is presented, in order to answer the question of the acoustical intention of the builders. More than fifty churches have been visited and measured: data were collected as geometrical dimensions of the church, date of foundation, number and localisation of the potteries, resonance frequency of each pottery … Only half of the buildings was studied because of the lack of data on several of them: for example, potteries were out of reach, broken, or simply disappeared because of a recent restoration …

Nevertheless, the analysis of all these data gave some interesting - even surprising - tendencies which will be presented in the conference. According to us, some results seem to show that the builders had an empirical knowledge of room acoustics.

[1] R. Floriot, *Contribution à l'étude des vases acoustiques du Moyen-Age*, Faculté des sciences de l'Université d'Aix-Marseille, 1964, 131 p., (thèse de doctorat).
[2] Jean-Marc Fontaine, *Contribution à l'étude des vases acoustiques disposés dans les églises (XIe- XVIIIe s.)*, Mémoire de fin d'études, CNAM, Clermont-Ferrand, 1979.
[3] A. P. O. Carvalho, V. Desarnaulds, Y. Loerincik, **"**Acoustic behaviour of ceramic

SPECIAL SESSION S1
Acoustic potteries in ancient buildings *(continued)*

pots used in middle age worship spaces - A theoretical and laboratory analysis", *9th International Congress on Sound and Vibration (ICSV)*, Orlando (USA), juillet 2002, p. 8-11.
[4] A Carvalho, V. Desarnaulds, Y. Loerincik, *Effectiveness of acoustic pottery in churches.* Noise-Con. Portland (USA), 2001, p. 29-31.
[5] T. Zakinthinos, D. Skarlatos, "The effect of ceramic vases on the acoustics of old Greek orthodox churches", Applied Acoustics 68, pp1307–1322, (2007)
[6] Y. Henigfeld et M. Werlé, « Sourd comme un pot acoustique ? L'exemple des céramiques engagées dans les maçonneries médiévales à Strasbourg », *Archéologie Médiévale*, tome 32, 2002, p. 135-156
[7] A. Boato, "Indagini di archeologia dell'architettura su un edificio pluristratificato", *Cinque chiese e un oratorio. Restauri di edifici religiosi dal XII al XVIII secolo per Genova capitale europea della cultura 2004*, G. Bozzo (Dir.), Genova, 2004, p. 58-66.

19.00– 19.20 ***Acoustic pottery in medieval and modern churches and temples in Europe: the state of the knowledge***

Jean-Christophe Valiere[1], Benedicte Palazzo-Bertholon[2]
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The effect of pottery inserted in walls or roofs in churches have been debated by numerous authors, acousticians [1,2,3,4] and archaeologists as well [5,6]. In some experiments achieved in laboratory [1,3] or in real churches [2,3,4] the potteries were considered as Helmholtz resonators. In spite of the investigations, there is still no evidence of the efficiency of such disposals (voice amplification, reverberation diminution). In the same time, archaeologists and medieval historians have proved the real acoustical intention of monks and church builders. A chronicle of "Célestins de Metz" monastery in 1432 state that « [il] *fit et ordonnoit de mettre les pots au cuer, portant qu'il avait vu altepart en aucune église et pensant qu'il y fesoit milleur chanter et que il ly resonneroit plus fort* ». A second text from 1616 about the count book of the chapter of « Saint Denis de Vergy » [L'Intermédiaire, 1900] state : « *Payé 24 sols au tupinier de Belon pour trois douzaines de petits pots pour mettre dans la muraille du chœur, propres à faire résonner la voix* ». Researchers have found more than ten texts (at least in France) over the centuries which explicitly mentioned a probable acoustic role of potteries [7,8,9,10].
This subject still remains an interesting challenge of knowledge particularly in term of history of acoustics. Then, these last ten years, different studies were performed along Europe: A. Kottmann in Germany [6], V. Desarnaulds in Switzerland [3], A. Boato in Italy, T. Zakinthinos and D. Skarlatos in Greece [4] and a consortium of researcher in France coordinated by ourselves [10].
The aim of this session is to make a state of the knowledge on this ancient acoustical disposal. Archeologist and acoustician working on acoustic potteries

could be invited to speak as well as researchers specialised in church acoustics [11] or in acoustic history [12].

[1] Floriot René, « *Contribution à l'étude des vases acoustiques du Moyen-Age*, Faculté des sciences de l'Université d'Aix-Marseille, 1964.

[2] Fontaine, Jean-Marc. « *Contribution à l'étude des vases acoustiques disposés dans les églises (X-XVIIIème s)* », Mémoire ingénieur CNAM. Juin 1979.

[3] Desarnaulds Victor, « *De l'acoustique des églises en suisse – une approche pluridisciplinaire »*, Lausanne, Ecole Polytechnique Fédérale de Lausanne, (thèse n°2597), 2005

[4] Tilemachos Zakinthinos, Dimitris Skarlatos, "The effect of ceramic vases on the acoustics of old Greek orthodox churches", University of Patras, Department of Mechanical Engineering, Rion Patras, Greece, Applied Acoustics 68, (2007)

[5] HENIGFELD (Yves), WERLE (Maxime), « Sourd comme un pot acoustique ? L'exemple des céramiques engagées dans les maçonneries médiévales de Strasbourg », Archéologie Médiévales, 32, 2002, p.135-156.

[6] Aline Kottmann, *Die Schalltöpfe von Meschede. Ein Keramikensemble aus der spätkarolingischen Stiftskirche St. Walburga*, Thèse de Doctorat, Eberhard-Karls-Universität Tübingen, Fakultät für Kulturwissenschaften, Institut für Ur- und Frühgeschichte und Archäologie des Mittelalters, Abteilung Archäologie des Mittelalters, Tübingen 2004.

[7] B. BERTHOLON-PALAZZO and J.-C. VALIERE, « Résonance et correction de la voix parlée et chantée : les dispositifs de vases acoustiques dans les édifices médiévaux et modernes : (Proposition d'une approche interdisciplinaire) », PRISMA, ed. 2009.

[8] P. CARVALHO, J.-C. VALIERE J.-C. et B. BERTHOLON-PALAZZO, « Les vases acoustiques dans les églises médiévales : analyse des sources et études de cas », *VIIème Colloque Biennal de Pommiers en Forez*}, Juin 2009.

[9] B. PALAZZO-BERTHOLON, J.-Ch. VALIERE, « Les vases dit acoustiques dans les églises médiévales : un programme d'études interdisciplinaire », in Burnouf J. dir., L'Europe en mouvement, Actes du 4e colloque tenu du 3 au 8 septembre 2007. http://medieval-europe-paris-2007.univ-paris1.fr/B.\%20Palazzo-Bertholon\%20et\%20al..pdf.

[10] B. PALAZZO-BERTHOLON, J.-Ch. VALIERE, « Archéologie du son, les dispositifs de pots acoustiques dans les édifices anciens », Numéro spécial du Bulletin Monumental, , tome 169 (III), octobre 2011

[11] CARVALHO (Antonio P. O.), "Relations between rapid speech transmission index (RASTI) and other acoustical and architectural measures in churches", Applied Acoustics, 58, 1999.

[12] Baskevitch François, Les représentations de la propagation des sons, thèse de l'université de Nantes, 2008.

9.00 - 10.40 **PAPER SESSION AM4**
Analysis & Modeling
Chair: *Nikos Tsinikas, University of Thessaloniki, Greece*

9.00 - 9.20 ***Acoustics and architecture in ancient open air theatres***

Nicola Prodi, Andrea Farnetani, Roberto Pompoli, Patrizio Fausti
Dipartimento di Ingegneria, Università di Ferrara, Ferrara, Italy

In the years 2000 there has been a flourishing of studies and projects concerning the acoustics of western ancient theatres, and especially those in the Mediterranean basin. In particular the EU project ERATO and the Italian project ATLAS focused on these spaces of performance. The interest of the acousticians was devoted to better know how they sound, to auralize them under several configurations and to clarify their acoustical evolution during the course of history. In this context the Engineering Department, University of Ferrara was involved in several activities such as in situ acoustical measurements, anechoic recordings of music samples and was in charge of detailed scale model researches. One of the main outputs of this long engagement was a clear view of the interplay of acoustics and architecture in open theatres from the most simple Greek design theatres to the more sophisticated Roman ones. It was found that typical acoustical conditions can be expected in accordance with a specific theatre layout. These findings will be reviewed in the work with hints to their relevance to the present usage of such spaces especially in view of the installation of a sound system to support the modern performance.

9.20 - 9.40 ***Oiniades ancient theatre acoustical assessment***

George Cambourakis
Electrical & Computer Engineering Dept., National Tech. Univ. of Athens, Athens, Greece

The Oiniades ancient theatre was built circa 330 BC with a second phase starting most probably circa 300-250 BC. It has almost concentric rows of seats with a capacity of 4640 spectators. For the assessment of the Oiniades ancient theatre acoustics the following procedure was followed: (1) An electronic model was built from the excavation initial drawings and on-site theatre geometry measurements. (2) Acoustic field simulation of the computer-restored theatre was studied and compared with on-site recitation experiences, (3) Extensive acoustic measurements were taken in the actual ancient theatre location in order to compare the simulation outcomes with the results of the measurements.
The electronic model for the Oiniades ancient theatre was built using AUTOCAD drawing program. The theatre geometry elements were transferred in the electronic model from the excavation drawings. From the restoration drawings, the photos of theatre remnants, and imaginary rendered architectural models, the “koilon” of the theatre can be measured precisely as there is adequate evidence of its geometry. Most of the theatre seating rows are preserved in such good condition that permits contemporary drama performances to be held. From the acoustic simulation of the theatre it was found that the theatre’s overall speech intelligibility is optimum for the majority of the seats. Furthermore, some indications about the acoustic performance for music performances are also provided.

PAPER SESSION AM4
Analysis & Modeling *(continued)*

9.40 – 10.00 ***A modern reading of ancient theatres architecture***

F. Gugliermetti, F. Bisegna, A. Carraro
Sapienza University of Rome, Via Eudossiana, Rome, Italy

The ancient theatres, the cradle of past civilization, are now living structures and highly required by the world of contemporary entertainment. They still retain the charm of an architectural and detailed sound while showing, in some cases, obvious signs of passing time.
This paper presents a summary of the acoustic qualities of these spaces, oriented to the identification and evaluation of design criteria operated by the builders of the past and to the determination of best suited interventions aimed at recovering the original sound.
The acoustic qualities of the considered environments were obtained by analyzing the impulse response of receivers placed within a grid of points.
From the comparison of experimental collected data, also developed in the form of global indexes and local assessment, it was possible to identify the main architectural and geometrical features that characterize the acoustics of ancient open-air theatres. This analysis resulted in a critical reading of the techniques about plays and types of representation found in ancient texts by Vitruvius and Aristotle. From the comparison of these spaces it is possible to understand the historical evolution of the geometry of the theatres and the past and present design choices, as well as developing, using appropriate numerical simulations, remedial measures aimed not only at using this structures in a modern way, but also at recreating lost in time atmospheres.

10.00– 10.20 ***Virtual acoustics and performance Spaces in Medieval English Drama***

Mariana Lopez, Sandra Pauletto, Gavin Kearny
Department of Theatre, Film And Television, The University Of York, York, UK

The relationship between acoustics and secular theatre in the Middle Ages has been somewhat neglected. This is most likely a consequence of the fact that medieval theatre was performed making use of structures temporarily assembled in outdoor spaces, such as streets. However, this does not imply that the space available and the structures used could not have been modified or built with the intention of improving acoustic conditions.
The present paper forms part of a project that proposes the employment of virtual models to attempt to reconstruct the acoustics of the performance spaces used in the York Mystery Plays, which are a series of forty-eight plays that were performed on wagons in the streets of the city of York (England) from the fourteenth to the sixteenth century. The present paper investigates the acoustic characteristics of Stonegate (a street in York used for the performance of plays), focusing on the reconstruction of the acoustics of this space in the late Middle Ages. An acoustic analysis of the Stonegate as it exists today is performed using impulse response measurements to determine the soundfield propagation. Multiple measurements at the same spot are made with the objective of increasing the signal-to-noise

ratio. Once the data are acquired, a virtual model of the street is created and then altered to match the characteristics of the medieval Stonegate, which can be sourced from archaeological studies of the city of York. Impulse responses were generated from the virtual model and compared to those of Stonegate today using ISO-3382 acoustic parameters. This project utilises techniques that have been applied to the study of the acoustics of ancient theatres, particularly in the ERATO project, and looks into the challenges of applying them to different historical period and in the context of a city street space.

10.20– 10.40 ***The Acoustics of the Ancient Theatre of Hephaistia – Limnos Island, Greece***
Theodoros Niaounakis
Acoustic consultant, Athens, Greece

The ancient stone theatre of Hephaistia is located to the northeast of Limnos Island, Greece and is dated back to the end of the 5th- beginning of the 4th century BC with additions/modifications during the Hellenistic and Roman periods. Works for the enhancement/restoration of the theatre were carried out during the period 2000 – 2004 by the K' Ephorate of Prehestoric and Classical Antiquities and after 2300 years, in the summer of 2010 hosted its first performance with the ancient Greek tragedy of Sophocles,"Oedipus Tyrant".
The evaluation process of the acoustics of the ancient stone theatre of Hephaistia includes:

- An objective assessment of its acoustics, based on the measurement and analysis of a number of acoustical parameters used for the evaluation of auditoriums.
- The development of an acoustic computer model of the theatre which is used to compare its simulated acoustic performance with measurement data obtained on site. The computer acoustic modeling of the theatre was also used to evaluate the effect of occupancy and various hypothetical treatment scenarios.
- A subjective assessment of its acoustics from a performer's point of view comparing their subjective experience during the performance of Oedipus Tyrant with that obtained from the performance of the same Greek tragedy in other ancient theatres such as the ancient theatre of Epidaurus.

SPECIAL SESSION S2

11.00- 12.20 **Analysis, Measurement & Modeling of Epidaurus Theatre**

Chair: *Jens Holger Rindel, Odeon A/S, Scion-DTU, Denmark*

11.00– 11.20 ***Studies on Epidaurus with a hybrid room acoustics modeling method***

Tapio Lokki, Alex Southern, Samuel Siltanen, Lauri Savioja
Department of Media Technology, School of Science, Aalto University, Espoo, Finland

The acoustic response of a virtual 3D Epidaurus model is simulated with a hybrid acoustic modelling method. Low frequencies, up to 500 Hz, are simulated with a 3D FDTD method that inherently accounts for wave phenomena, such as diffraction and interference. The high frequencies are predicted with the acoustic radiance transfer method. Our current understanding of concert hall acoustics is applied in the analysis of the computed impulse responses. This leads to a discussion on the contributing factors behind the incredible acoustics of ancient theaters.

The predicted results are both visualized and auralized. The auralization is performed using a multichannel 3D loudspeaker setup, enabling soundfield rendering of the modeled directional wavefield components.

Those processes in conjunction with the consideration of concert hall acoustics help to contribute a better understanding of the acoustics in Epidaurus and in ancient theatres in general. More specifically, the paper will analyze the seat dip effect and early reflections and how they differ from normal concert halls. Such analysis will raise the current understanding of the acoustics of ancient theaters.

11.20– 11.40 ***Theatre of the Sanctuary of Asklepios at Epidaurus and the Theatre of Ancient Epidaurus: Objective measurements, computer simulations and listening tests***

Kostas Angelakis, Jens Holger Rindel, Anders Christian Gade
Danish Technical University, Denmark

The results of in situ acoustic measurements in various source-receiver configurations at both the Theatre of the Sanctuary of Asklepios at Epidauros and the Theatre of Ancient Epidauros are presented. The measurements are compared to simulations of the theatres created with the use of the ODEON software. In addition, the models are used in order to investigate the effect of the addition of a stage on the acoustic properties of the theatres.

Furthermore, the results of a series of listening tests (*) designed in order to study the effect of the amplification on subjective aspects of the acoustical “character” of the theatre (e.g. the perception of space based only on auditory cues, intimacy), are presented. The relation of the outcome of the listening tests with objectively measured acoustic parameters (e.g. SPL, Clarity) is also investigated.

(*) The material (i.e. audio tracks) used for the purpose of the tests was obtained from binaural recordings of amplified and non amplified performances in both theatres.

SPECIAL SESSION S2
Analysis, Measurement & Modeling of Epidaurus Theatre *(continued)*

11.40– 12.00 ***Measurements and Analysis of the Acoustics of the Ancient Theatre of Epidauros***

Stamatis Vassilantonopoulos+, Panagiotis Hatziantoniou[1], Nicholas-Alexander Tatlas[1], Telemachos Zakinthinos[2], Dimitris Skarlatos[2], John Mourjopoulos[1]
[1]Electrical and Computer Engineering Dept., [2]Mechanical and Aeronautical Engineering Dept., University of Patras, Patras, Greece

Recent results are presented, from acoustic measurements performed in the ancient open theater of Epidauros. These measurements were obtained using modern techniques, allowing evaluation of numerous acoustic parameters for the theater, such as: Clarity C-80, Definition D-50, RASTI, IACC, LEF, etc. These measurements and results are also compared to the results obtained from a computer acoustic simulation of the theater's acoustics, for similar source – receiver positions. The analysis of the results, illustrates many novel aspects of the theater's acoustic properties, such as the pattern and mechanism for the early reflections, the spectral response of the theater, aspects of time-frequency response interaction and aspects of the spatial impression. The results restate the well-known exceptional acoustic quality of the theater for speech, with speech intelligibility remaining nearly perfect at all listener positions.

12.00– 12.20 ***Acoustic and environmental parameter measurements in Epidaurus Ancient Theatre***

Sotiris P. Psarras, Mercourios Kountouras
Acoustic consultants, Athens, Greece

Trying to understand more deeply the influence of environmental factors and how they affect, in 24 hour basis, the behavior of airborne sound in the theater of Epidaurus, and the constantly changing environmental parameters such as:
- relative humidity,
- air temperature,
- wind velocity gradients on sound propagation,
- wind direction,
- breeze,

We will install three portable weather stations for a period of 36 hours at three different elevation points of the theater for data recording and further processing. At the same time we will try to record with the thermal camera color renderings to be generated during a 24hour basis on the surfaces of the hollow and marble stairways of the theater. We will also simultaneously proceed at acoustic measurements using dodecahedrons as a sound source mounted on the hollow and three individual two-channel portable sound level meters Bruel & Kjaer 2270 as sound receivers located at three different elevation points of the theater for recording data and further processing. The completion of the measurements will be presented on charts and graphs. We hope that this experiment will take place at a depth of 5 years and at different times of the year in order to identify as many items relating mainly to the influence of environmental conditions and the propagation of sound waves in Epidaurus ancient theater.

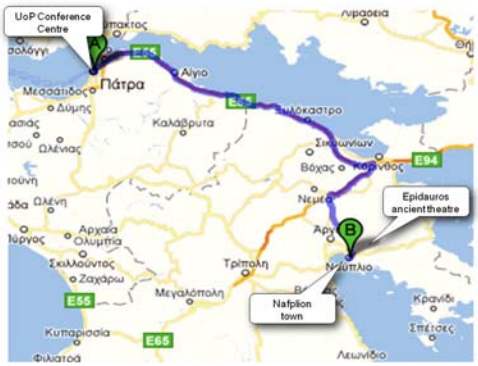
16.40–18.30 **WORKSHOP W2**
Epidaurus ancient theatre

In situ actor-demo / acoustic measurement
in collaboration with the Municipal and Regional Theatre of Patras (DIPETHE)

The Theatre of Epidaurus ("Epidauros" in Greek), is an appropriate location for this closing session. Most acousticians, archaeologists or even non-specialists agree that the ancient Greek theatre of Epidauros, exemplifies the acoustical, functional and aesthetic qualities that are discussed throughout the Conference. Given its well-preserved state, the theatre is one of the most well-known and is a regular tourist attraction.
The theatre is located in the region of Argolis, at the eastern Peloponnese at approx. 190 Km from Patras (see map). The theatre was constructed late in the 4th and early in the 3rd century BC, with a second construction phase during the mid of the 2nd century BC, possibly being the design of architect Polyclitus. Even in the ancient times it was considered by Pausanias to be the most harmonious and beautiful open-air theatre, features related to the structure's adaptation to the shape of the hillside and its famous acoustic quality. The theatre has a capacity of 13000–14000 people and was initially used for solo singing, chanting, musical contests (mainly for solo instruments) and theatrical performances of ancient drama plays. Similar types of activities are still currently entertained in the site during the summer months.
The table below gives some of the geometrical properties of the theatre.

Radius (m)	Slope angle (^{0})	Rows of seats	Orchestra radius (m)
59	Φ_1=26.2 (lower) Φ_2=26.5 (upper)	55	9.775

For the Workshop, the participants will have a chance to familiarize with the theatre acoustics. The actor *Mr Giannis Voglis, Artistic Director of the Municipal and Regional Theatre of Patras* will recite typical excerpts from ancient drama, recreating a typical theatrical performance. Acoustic impulse response measurements taken earlier via omnidirectional and dummy head microphones, along with the map of the measuring positions will be made available to participants along with the Proceedings CD. However, if any further measurements are required to be taken at the theatre, then this can be accommodated during the Workshop (*)



(*) after prior notice, the measuring equipment will be set-up at the theatre in advance of the Workshop

POSTER SESSIONS

MONDAY, SEPTEMBER 19th

POSTER SESSION P1
Conference Centre foyer
Chair: *Lamberto Tronchin, University of Bologna, Italy*

P1
Monday
10.20-11.00

Investigations of the Acoustics of the ancient theatre of Epidauros

George Cambourakis[1], Alexandra Sotiropoulou[2,3] , Anastasia Savvopoulou[2,4] , George Poulakos[2,3], Jannis Tzouvadakis[3], Athanasios Stamos [3]
[1]Electrical & Computer Engineering, National Tech. Univ. of Athens, [2]School of Architecture, National Tech.Univ. of Athens,
[3]School of Civil Engineering, National Tech. Univ. of Athens, Athens, Greece
[4]Bartlett School UCL, London, UK

Past and more recent scientific studies have focused on the acoustics and architecture of the ancient Greek theatres, thus contributing to our knowledge about their design principles. The present study investigates the acoustics of the ancient theatre of Epidaurus, which was designed exclusively for drama performances. In particular the present study focuses on the analysis of speech intelligibility as an important parameter for the assessment of ancient theatre acoustics. First, an electronic 3d model of the ancient theatre was produced via available software (AUTOCAD); also simulation of the acoustic field of the above mentioned model was attempted using available software (EASE). Secondly field measurements were carried out for the following acoustic parameters: Sound Trasmission Index (STI), Articulation Loss of consonants (ALcons), Reverberation time (T30, sec), Early Decay Time (sec). The results cast some light on the question of actors' location and orientation on stage, regarding the acoustics of the theatre. The results are also interpreted in terms of the architectural design and features of the auditorium.

P1
Monday
10.20-11.00

Experiments on Room Plane Wave Decomposition for Virtual Acoustics

Ana M.Torres[1], Basilio Pueo[2] , Jose Javier López[3]
[1] Electrical, Electronics, Control Engineering y Communications Dept., Universidad de Castilla-La Mancha, [2] Communication and Social Psychology Dept., Universidad de Alicante, [3] Instituto de Telecomunicaciones y Aplicaciones Multimedia. Universidad Politecnica de Valencia, Spain

Throughout history, emblematic theatres, concert and opera halls have disappeared and with them their acoustic behavior. In some on them, thanks to technicians and scientific that measured the rooms before its loss, now it is possible to recreate its behaviour. The more sophisticated recording techniques the better the final recreation. Within the different recording techniques, arrays of microphones are used to obtain proper spatial resolution and comprehensive information for a later reproduction of the sound field accurately. Contrary to single impulse response measurements, which are not capable of providing angle-dependent information of reflections, an array of microphones allows to capture impulse responses coming from a variety of directions. This multiple data is then analyse to obtain a true acoustic footprint of the hall, including all sort of imperfections, reflections and

POSTER SESSION P1 (*continued*)
Conference Centre foyer

other acoustic spatial characteristics. In this paper, a recent procedure of measuring spatial sound characteristics by means of circular array is presented. In order to have a general and more flexible description of the sound field not linked to specific microphone positions, decomposition of the sound field into plane waves is considered. For a circular array, the Kirchhoff-Helmholtz and Rayleigh integrals are used to later extrapolate the sound field using cylindrical harmonics. This tool can be regarded as making an acoustic snapshot of each room in such a way that any process could be virtually recreate in it, such as reproduction sounds, technical analysis or listening from anywhere in the room. Furthermore, different room sound fields and auditoriums have been analysed through the proposed decomposition in plane waves using cylindrical harmonics, for which a deep study and implementation of circular arrays have been described. With these results, a complete acoustical description of the sound field inside the room is acquired, which allows designers to investigate benefits but also possible defects or unwanted reflections to be corrected. Finally, different kind of rooms have been measured and analyzed in order to validate the method and to be used in virtual acoustics and 3D sound reproduction.

POSTER SESSION P2
Conference Centre foyer
Chair: *Antonino Di Bella, University of Padova*

P2

Tuesday
17.20-18.00

Acoustics and Intelligibility of the Dionysus Ancient Greek Theater at the Acropolis of Athens

George E. Cambourakis[1], Sotirios A. Dalianis[1], Alexandra Sotiropoulou[2]
[1]School of Electrical and Computer Engineering, [2]School of Architecture, National Technical University, Athens, Greece

In the ancient theaters, the sources that create the sound field are the speakers (actors), the *ancient dance* members (chorus, dancers, musicians) and the crowd of spectators. Thus, what will be studied is the acoustic behavior of the ancient theater space, mainly, to voice sound signals. The parameter in attention is intelligibility, because, this describes the quality of communication between the main performance factors (i.e. actors, musicians) and the audience. Today, the prediction of articulation indicators may be produced with a series of measurements, without the presence of listeners. The main parameter that is calculated is intelligibility. Actually, an estimate of clarity in the transmission of the audio signal is produced, which is associated to the intelligibility capabilities of the average listener. These elements feed simulation models of the acoustics attributes of space and calculated with the help of computers.
The simulation of the ancient Greek theater via computational models, gives the possibility of studying the associated statistics and in particular using measurements of different source placements in the theater. The results are useful for other

research sectors (minus the acoustics) and can used to extract conclusions with regard to the theatrical practice in the ancient word. This method, together with the study of the resulting comparative elements, allow us for example, to formulate the opinion that the statistics with regard to intelligibility, of the Epidaurus Theater, are much better than that of the Dionysus Theater, for reasons that will be exposed in this presentation.

P2
Tuesday
17.20-18.00

A method for the acoustic modeling of past soundscapes

Braxton Boren, Malcolm Longair
Cavendish Laboratory, University of Cambridge,
Cambridge, UK

This paper investigates the use of geometric simulation algorithms to model the acoustics of a church as it would have sounded in the late 16th century. Based on measured acoustic parameters, an average absorption parameter is developed for the heterogeneous walls of the Church of the Ospedaletto, obtaining a good match between the simulated model and modern acoustic measurements. Using these data, the model is altered to simulate the church's acoustics before the large organ gallery was installed in the late seventeenth century. The model predicts an increase in EDT and C80 for the church's choir's position at the high altar. This difference presumably results from early reflections off the wall behind the altar, the organ gallery's present location. This method allows a high degree of confidence in the model's ability to reconstruct accurately the church's soundscape as it would have been experienced in the Renaissance.

SPECIAL EVENTS

MONDAY, SEPTEMBER 19th - TUESDAY, SEPTEMBER 20th

DEMO ROOMS
Conference Centre

Interactive auralisation terminals
Demonstrations by the ERATO project and the University of Patras Audiogroup

SUNDAY, SEPTEMBER 18th - WEDNESDAY, SEPTEMBER 21th

ANCIENT THEATRE SLIDESHOW
Old Municipal Hospital*

A tour of ancient theatres
A slideshow presentation of 60 ancient theatres from Greece, Turkey, Italy, France, Spain, Cyprus, Bulgaria, Albania, Egypt, Syria, Jordan, Israel, Libya, as they are today.

** the show will be open to the general public. It will be also relayed in the Conference foyer screen*

MONDAY, SEPTEMBER 19th - TUESDAY, SEPTEMBER 20th

THE WORK OF S.VASSILANTONOPOULOS
Conference Centre foyer

Acoustic simulations of ancient theatres and ritual spaces
A poster presenting the work of the late Assist. Professor and Honorary Conference Chairman, Stamatis Vassilantonopoulos

CONFERENCE DINNER

21.00, TUESDAY, SEPTEMBER 20th

A 3-course dinner will take place in a venue that will be announced. Tickets for the dinner will be priced at 30 Euros and purchased from the Conference secretary stand at the Foyer. A coach will be available to transport participants to and from the restaurant.

Further details to be announced at the Conference

CONFERENCE TOURS

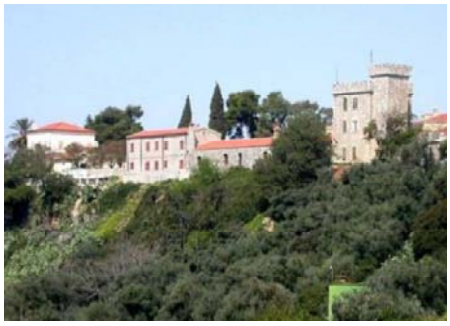
MONDAY, SEPTEMBER 19th - TUESDAY, SEPTEMBER 20th

Tours for accompanying persons will take place at important sites in the area. The duration of the tours will be approximately 3 hours and details will be provided from the Conference secretary stand at the Foyer.

TOUR 1: **New Archeological Museum of Patras**

Just outside the city center, is the New Archaeological Museum. The remarkable exhibits of the new Museum introduce the history of Patras to the public, dating from the prehistoric times to the late Roman times. The exhibition consists of three thematic sections, which unfold throughout the Museum's rooms: the Private Life Gallery, the Nekropolis and the Public Life Gallery.
The museum includes a small auditorium of 150 seats, a showroom and a souvenir shop.

TOUR 2: **The Achaia Clauss winery**



On a green hill, eight kilometres away from Patras, is the castle-winery of Achaia Clauss, a chateau built in 1854. The stone buildings, the huge oak barrels, containing century-old mavrodafni wine, the traditional wine cellar for welcoming visitors and the unique scenery with the magnificent view, attract around 200.000 visitors on an annual basis. One of the factory's guides will be expecting you at the entrance, and you will also have the opportunity to taste some of the wines.

Further details to be announced at the Conference