Performing Theatre. Experimental methodology for the simulation of the multisensory experience at the Roman Theater of Amman

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Abstract

This study presents the 3D reconstruction of the Roman Theater of Amman, ancient Philadelphia, through a representative architectural model from which acoustic simulations have been carried out. An exhibition will provide site-specific installations and artifacts for digital and tactile interaction via multimedia and tactile models. The procedure involves virtual 3D reconstruction in a game engine simulation environment supported by a scientific approach given by the acoustic simulations, which recreate the listening sensation that would have been in the theater at its original shape. The auralization process, similarly to the visualization process, allows the reproduction of sounds rather than images. The game engine simulation tests the analog-digital model's staging and interaction design methodologies, starting from the tactile discovery of some props, such as masks. The investigation leads to reflect on which representative models can perform verification and subsequently communicative function, primarily in the visual dimension of the reconstructed architecture, synthesis of apparent oppositions between theoretical models (see Vitruvius) and built form. The new technological paradigms allow a dynamic and multi-sensorial experience of heritage, including those intangible values and stories that made this architecture spectacular.

Keywords
roman theatre, cognitive model, acoustic simulation, 3D replication, Amman, Jordan.

The Roman Theatre of Amman, view from the piazza. Picture by Giuseppe Amoruso.

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Introduction

What brought the cities of Roman Palestine and the province of Arabia during the 2nd and 3rd centuries AD to build expensive architecture like theaters?
For independent Greek cities, the construction of a theater was an act of great social significance; on the one hand, it expressed the spirit of the polis; on the other, it strengthened the citizens' sense of belonging through the collective experience of watching theatrical performances. According to Homer, the true strength of the warrior is to be imagined visually as "splendid to behold", to arouse the vision strength in those representations. In the epic tale and theatre, a population of spectators is thus formed, fueling the extended sense of curiosity and its seductive and pervasive power, which fuels the desire to see and know in a democratic aesthetic form.
The construction of a theatre required complex engineering skills and huge expenses due to the need to contain a large crowd like what occurred in Amman, the ancient Philadelphia of Decapolis [Chancey et al. 2001], designed to accommodate around 6000 spectators.
The theatres of the Roman Palestine and in the Arabian Province, erected by Trajan in 106 AD, were built in a period time of nearly three centuries, between the second half of the 1st century BC and the 3rd century AD. These constructions can be found in four different regions: the kingdom of Judea, the kingdom of Nabataeans (extended to the south-east side of it), in the Hellenistic cities and in the territories under the dominion of Rome. Ome of the most interesting and prosperous period is recognised with the Hellenism, going from the end of the 1st century AD to the 2nd century AD. Well integrated in the urbanistic design of the city is the Roman theatre of Philadelphia, built in the most important city on the south side of *Decapolis*.

Digital models for the multisensorial experience inside the Roman theatre.

The international partnership between Italy and Jordan allowed a very detailed study on the Roman theatre of Amman, after a century of excavations. The contemporary concept of cultural heritage includes tangible and intangible complexity of the building in its nature, along with the social function of offering inclusion and accessibility; however, what are the most appropriate tools that a researcher has to use for the representation of the models?
The recommendations given in the charter of Seville (2011) and in the charter of London have been used for the digital visualization of the cultural heritage building (2009) [Amoruso et al. 2023]. It was possible to rase some hypotheses regarding the architectural shape of the scenic building based on previous reconstruction alterations, as graphically highlighted. The representative models used by the archaeologists are composed of visual experiences, mainly based on a function of verification and communication as synthesis of apparent conflicts between theoretical (Vitruvius), typological (Greek, Roman and/or a combination of both), and built models. The reconstruction is a method for assessing, checking and compare data, as well as analytically checking the hypotheses, visualizing arguments and incongruencies in relation to the reconstruction. It should be remembered that the research approach is to be clear, based on resources, history, graphical and photographical materials, in order to build a database easily accessible and searchable [Amoruso 2023].
The state of conservation related to the Roman theatre was already documented in the 1700 and at the beginning of 1800 by travellers. Butler published in 1907 one of the first pamphlets on the drawings of the building, as it was before the excavations [Butler 1907]; however, the documentation includes also different mistakes related to the underground part.
The Italian expedition directed by Bartocchi, conducted between 1927 and 1938, brought to different archaeological excavations in Amman, such that Ceschi redrew again the theatre from scratch [Botarelli 2015]. The comparison between Butler and Ceschi' drawings show incongruencies regarding the rebuilt lower part of the theatre and even more regarding the scenic building [Almagro 1983].

This first campaign of archaeological excavation brought to light the original shape of the ima cavea, the orchestra and the lower part of the scenic building, although a complete reconstruction where no documentation existed was carried out for the rest of the theatre. After the restoration works, a critic publication about the reconstruction project was published in 1975 [Al-Fakharani 1975]. Despite it was referenced many times by literature [Frézouls et al. 1961; Isler 2017; Sear 2006; Segal 1995], the first analytical comparison was undertaken by Almagro, who highlighted the incongruity of the corridors system related to the access to *ima* and *media cavea*, the details of the first steps of *cavea*, orchestra and *pulpitum*, that were still buried at the time Butler and Ceschi, for which Almagro listed in detail the mistakes regarding the reconstruction models [Almagro et al. 2007].
The ancient theatre of Amman is to be considered a Roman theatre because the orchestra is not fully circular (as per the Greek theatres) but semicircular, and the *cavea* does not go over the limit signed by the diameter of this circle. The theatre is built by taking advantage of the natural slope of the hill, so that the widest area is erected by avoiding further artificial structures required for its stability. Both theatre and odeon of Philadelphia, as well as the northern theatre of Jerash, were built during the period of the Antonines emperors, specifically under Antoninus Pius and Marcus Aurelius [Segal 1995, p. 8].
Among many stories created around the spectacular shows of the Roman theatre of Amman, the principal focus is on the architectural structure with respect to the configuration of the scaena frons.
The front wall of the stage building, called *scaenae frons*, varied in design. The first prototypes were provided with straight and flat shape with three doors arranged symmetrically: the main entrance (*valvae regiae*), and two secondaries located at sides (*valvae hospitalia*).
In the theatre of Philadelphia the three entrances located in the center of curved niches, with the central niche to be larger in diameter. The stage building was composed of two to three orders of columns, to be equal to overall height of the *cavea*. It was possible to notice on site, especially where the building is more preserved, the joining point between the cavea and the walls of versurae that are on the same level. The *scaenae frons* was capped with a single roof inclined towards the *cavea* which rose above the stage floor and was extended between the two *versurae*. The roof was inclined by 45° and served to protect both *scaenae*

Fig. 1. The Roman Theatre of Amman, view from the *media cavea*. Picture by Giuseppe Amoruso.

frons and *pulpitum* from sunshine, and at the same time gave the impression to the spectators of an architectural and statuary wealth of *scaenae frons* [Segal 1995, pp. 24-25].

Acoustic function of architectural elements in a Roman theatre

Architecture and construction techniques influenced also the performative spaces. An example is given by the *opus cementicium* used by Romans to erect tall structures composed of different levels as well as the use of arch that allowed the realization of agile structure. This historical innovation in the field of construction brought Romans to develop the architectural elements of a theatre: the *proscenium* became a massive building, including also the *parascenia*, that had the function of providing ingress and exit of actors from the scene and was also organized onto two or three orders of columns. In terms of acoustics, the scenic building works as a favorable vertical surface that addresses the sound towards the cavea that otherwise would be dispersed in other directions [Bevilacqua, Fuchs 2023]. The addition of a coffered roof above the stage floor had the function of protecting actors from

Fig. 2. Architectural survey of the theatre, orthophoto showing the cavea and museum interiors. Elaboration by Giuseppe Amoruso and Andrea Manti.

Fig. 3. Architectural survey of the theatre, plan and orthophoto showing the *orchestra* and the water piping under the building. Elaboration by Giuseppe Amoruso and Andrea Manti.

adverse meteorological conditions (i.e. rain and sunshine) but its inclination had a hidden function of addressing and diffusing the sound towards the spectators.
Another typical and distinctive architectural element of a Roman theatre is the ambulatory (*ambulacrum*), accessible by a system of stairs and provided with doors (*vomitoria*). The ambulatory at the top level of the summa cavea was often covered with a columnated porch (porticus) that crowned all theatre. This was the space reserved to women and slaves [Izenour 1977].
In terms of materials, the choice of having fine marble finish contributes to reflect the sound from floor and steps surfaces, counterbalancing the absence of any roof that, differently from the odeon (*teatrum tectum*), would help to increase the perception of loudness and envelopment of sound [Beranek 1962]. The suspended wooden planks of the stage floor represented the first prototype of resonance box, since the void created between the wooden boards and the natural ground provided with stone cavities, reinforced the low frequencies [Caniato et al. 2018] and, consequently, what is subjectively known in acoustics as sound warmth.
The existing conditions of the Roman theatre of Amman lack several parts, especially the staging area related to the scenic building. This phenomenon raises different hypotheses regarding the characteristics of the construction elements that directly affect the acoustic response within a space. The analysis consists of understanding the sonic environment at its original shape under a scientific approach. It is through interdisciplinary work between researchers in architecture and acoustics that this goal became successful. Differently from the Greek theatre where the actor was free to perform across the orchestra, in the Roman theatre the actors were on pulpitum most of the time, meaning that the sound addressed to the cavea came mainly from the direct component in addition to the reflections hitting two surfaces: the stage/orchestra floor, and the vertical wall of the scenic building [Bellia et al. 2023].
Acoustic simulations have been carried out with Ramsete 3.12 software, which computes all the acoustic parameters as defined by ISO 3382 [ISO 3382-1] based on absorption and

Fig. 4. The Roman Theatre of Amman, view from the stage with the suspended wooden planks. Picture by Giuseppe Amoruso.

scattering coefficients, as summarized in fig. 9. Ramsete is a software based on image-source and ray-tracing algorithm, provided with pyramidal propagation with a triangular base. This principle can avoid errors at a high degree of reflection which tend to occur rather with conical propagation [Farina 1995]. Two virtual omnidirectional sound sources were integrated into the models, placed at a height of 1.7 m., one in the center of the stage floor and the other in the center of the orchestra. A number of 337 virtual microphones were uniformly distributed across the cavea as the main representative place for audience.
The spatial distribution maps have been computed for the main acoustic parameters that are highly dependent on the position taken across the seating area: speech and music clarity indexes (C50, C80), and strength (G).
It has been established by literature [Jordan 1981] that the clarity index is an acoustic parameter given by the ratio of the sound reflections arriving before 50 ms (for speech) or 80 ms (for music) and the sound energy arriving to the listener in the following instants. The optimal value for clarity is represented by 0 dB meaning that there is a perfect balance between early and late reflections. A certain tolerance is given, to be comprised between -2 dB and +2 dB, meaning that the sound is perceived more rumbling if the values of clarity are < -2 dB or very clear with accentuation of high pitches when the values of clarity are > +2 dB.
In the Roman theatre of Amman both C50 and C80 are within the optimal values when the cavea is fully occupied, as it is assumed to be in the past. A peak value of +3 dB has been found at the front rows of seats, as shown in fig. 10 (on the right), but it is considered a very negligible difference.
When the *cavea* is unoccupied the clarity indexes are down shifted by 2 dB, to be around -3 dB for C50, as shown in figure 9(a), and -2 dB for C80, as shown in figure 9(b); however, the condition of having the *cavea* unoccupied is not realistic since theatres and amphitheaters were very crowded by citizens who attended to spectacles on daily schedule.
In terms of strength (G), this acoustic parameter indicates how much sound energy arrives to the listener in function of its sound power level and distance running between source

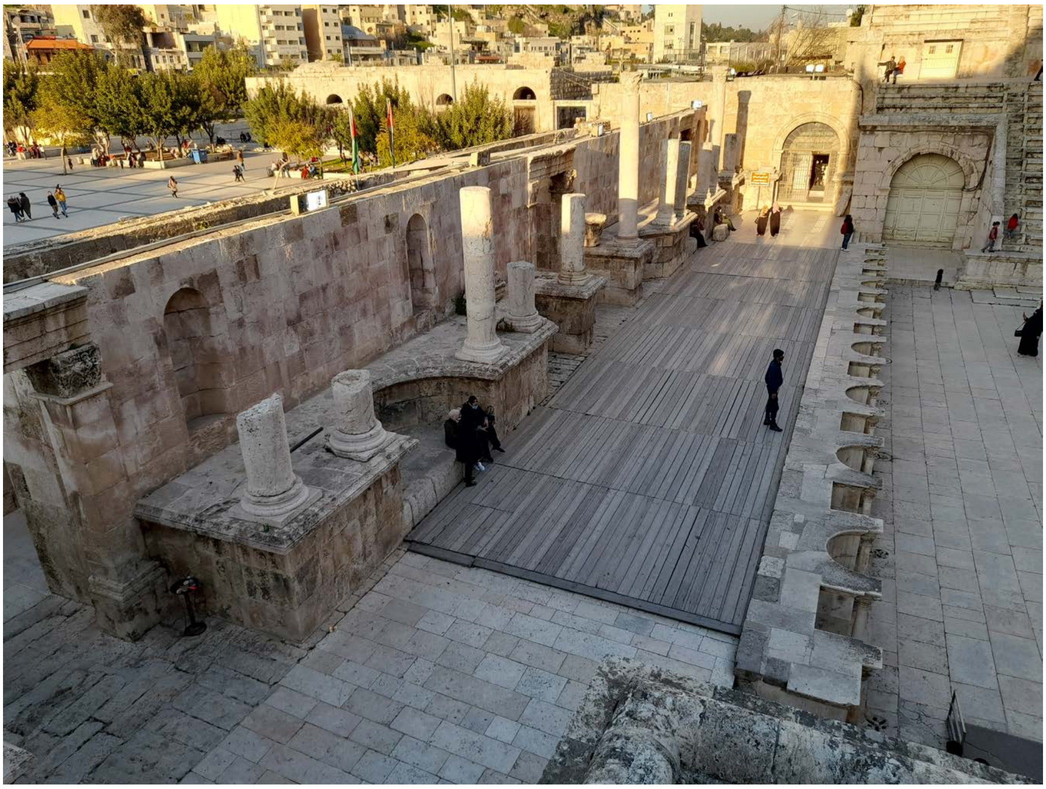

Fig. 4. The Roman Theatre of Amman, view from the stage with the suspended wooden planks. Picture by Giuseppe Amoruso.

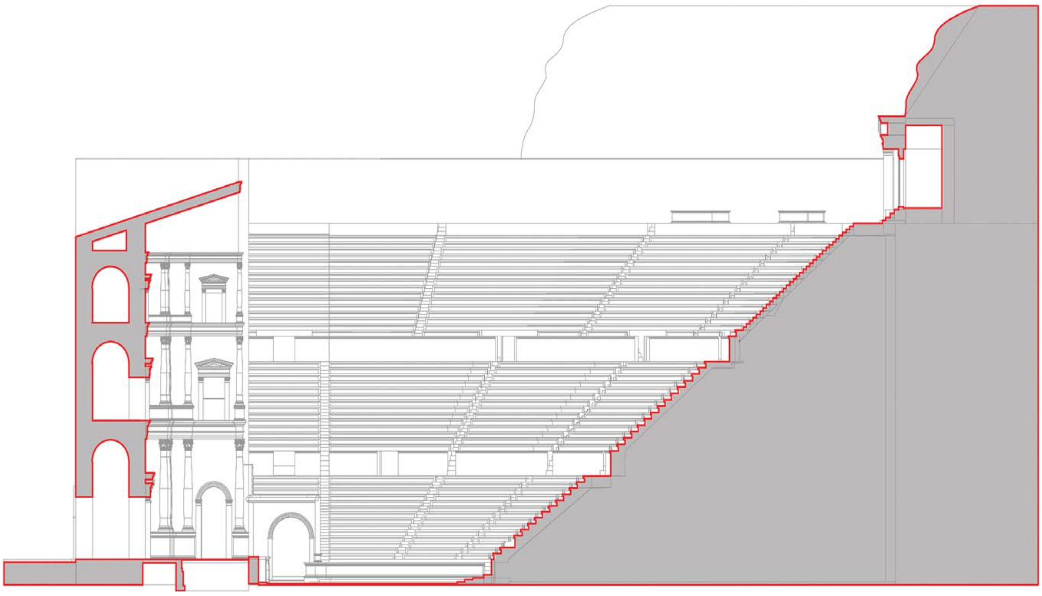

Fig. 6. 3D reconstruction of the *scaena* frons, orthogonal view along the central line. Elaboration by Polina Mironenko.

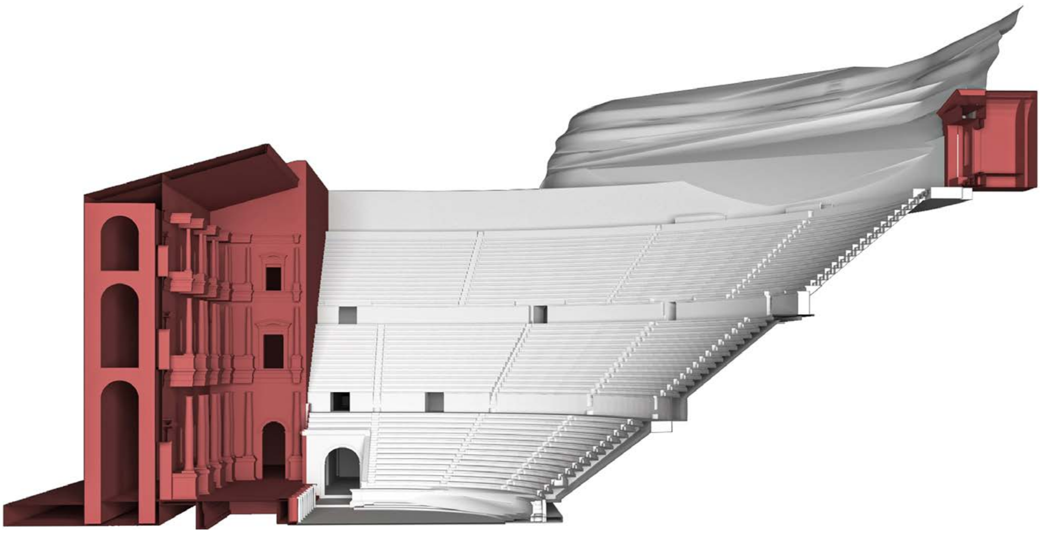

Fig. 7. 3D reconstruction of the *scaena* frons, perspective view. Elaboration by Polina Mironenko.

Fig. 8. 3D replica of a terracotta mask founded at the Roman Theatre, from the data acquisition at the Archeological Museum to the musealization proposal, printing a tactile model. Elaboration by Andrea Manti.

and receiver [Wenmaekers et al. 2015]. Fig. 11 shows that the G values in the Roman theatre of Amman as originally built are between +4 dB, as found in the seats closest to the orchestra, to -2 dB (when unoccupied) or -4 dB (when fully occupied) (fig. 11, on the left). These values are good to be in an open-air theatre provided with a dimension of the *cavea* external diameter equal to 94 m., if compared with other Roman theatres that have smaller size. Fig. 11 shows also that the decay curve of G values at 1 kHz, for a distance comprised between 12 m. and 45 m (fig. 11, on the right). The trendlines are found to be very similar between 0% and 100% occupancy, but with a downshift of almost 1.8 dB between the two scenarios. Particular attention should be paid to the closest distance, where no difference is found between 0% and 100% occupancy, but the divergence becomes more accentuated as far as the distance reaches 40-45 m. This trendline is typical of open-air theatres where the reflections from above-ceiling are missing and only the front and lateral reflections are good to support the G values.

Fig. 9. Absorption (in italic) and scattering (in bold) coefficients for all the materials considered for the acoustic simulations of the Roman theatre of Amman at its original shape. About Sound Absorption coefficients: Terrain/soil (from: Sikora et al. 2010); Tuff stone and Timber wood (from: Saccenti et al. 2022); Audience (from: Barron 2010).

Materials	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Terrain/soil [3]	*0.06*	*0.20*	*0.32*	*0.55*	*0.60*	*0.55*
	0.10	**0.11**	**0.11**	**0.12**	**0.12**	**0.12**
Tuff stone [4]	*0.01*	*0.06*	*0.05*	*0.02*	*0.08*	*0.05*
	0.10	**0.11**	**0.11**	**0.12**	**0.12**	**0.12**
Timber wood [4]	*0.08*	*0.20*	*0.10*	*0.05*	*0.03*	*0.02*
	0.15	**0.12**	**0.10**	**0.08**	**0.04**	**0.04**
Audience [5].	*0.51*	*0.64*	*0.75*	*0.80*	*0.82*	*0.83*
	0.20	**0.25**	**0.37**	**0.40**	**0.38**	**0.31**

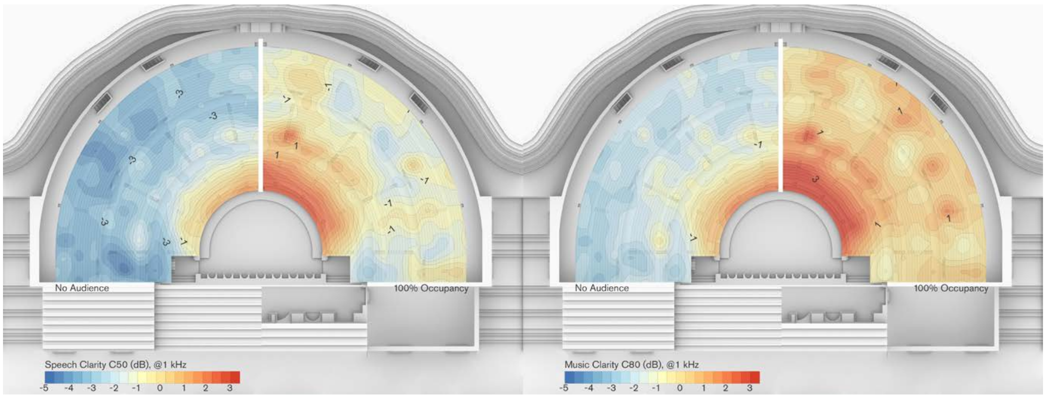

Fig. 10. Spatial distribution maps of speech clarity (on the left) and music clarity (on the right) indexes, plotted at 1 kHz. Elaboration by Antonella Bevilacqua.

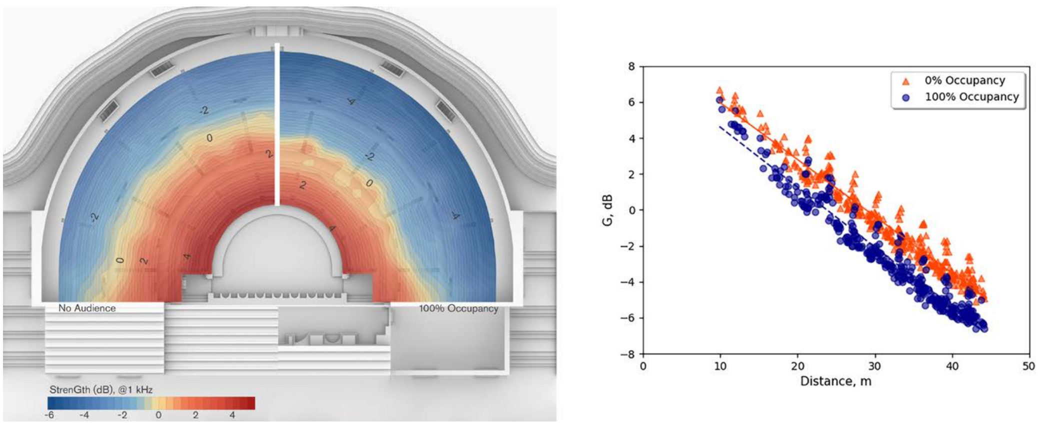

Fig. 11. On the left: spatial distribution maps of strength; on the right: decay of values in function of distance from the sound source placed in the center of *pulpitum*, plotted at 1 kHz. Elaboration by Antonella Bevilacqua.

Conclusions

In *Software Takes Command*, Manovich asks "What happens to the idea of a "medium" after previously media-specific tools have been simulated and extended in software? Is it still meaningful to talk about different mediums at all? Or do we now in ourselves in a new brave world of one single monomedium, or a metamedium? What is "media" after software? architects working with the media of 3D computer graphics started to imagine different things than their predecessors who used pencils, rules, and drafting tables" [Manovich 2013]. With the help of new technologies, starting from the logical and cognitive model, updated with the data collected during the survey phase, it is possible to develop a reconstructive model with a high level of accuracy and addressed to a new audience of "spectators and listeners". Future visitors, "new spectators", will be made participants in a visionary, imaginary, acoustic cultural experience, experiencing, alternatively, the background in the voice of the actors as well as the spectators according to the different social categories of the *polis*. Precisely because the word "theatre" derives from the ancient Greek *theatron*, this word was originally used to describe the spectator, the act of seeing a show, the vision rather than the building. The Greek term for "spectator" was *theorós* which has the same root as theory, a term referring to the concept of "seeing" (*theoréin*) and therefore to watching a show in a theatre, namely the *théatron.*
Could the simulated theatrical space, thanks to interaction and technologies, be a new theatre? the significant power of the language of representation and its multimedia forms appears to be the main scientific theme in the rediscovery of values and meanings also linked to intangible heritage and those human stories of the past. In their stories, Homer and Herodotus adopt a writing technique that amplifies the visual imagination of readers who transform themselves step by step into spectators while listening to the texts. It is an unconscious process but one that restores empathy and involvement, in fact in Greek "reading" is "recognizing" (*anaghinòskein*), writes Segal [Segal 1995]; It is precisely this act that creates the growing interest in this work of reconstruction and simulation.

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