Real-Time Animation of Ancient Roman Sites

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Abstract

In the presented article we discuss and detail the general methodological approaches, the reconstruction strategies and the techniques that have been employed to achieve the 3D interactive real-time virtual visualization of the digitally restituted inhabited ancient sites of Aspendos and Pompeii, respectively simulated using a virtual and an augmented reality setup. More specifically, the two case studies to which we will refer to illustrate our general methodology concern the VR restitution of the Roman theatre of Aspendos in Turkey, visualized as it was in the 3rd century, and the on-site AR simulation of a digitally restored Thermopolium situated at the archeological site of Pompeii in Italy. In order to enhance both simulated 3D environments, either case study presents the inclusion of real time animated virtual humans which are re-enacting situations and activities that were typically performed in such sites during ancient times. Furthermore, the implemented modeling and illumination strategies, along with the design choices that were operated regarding both the preparation of the textured 3D models of the sites and the simulated virtual humans, and concerning their optimization in order to suit the needs of a real time interactive visualization, will be equally presented.

Keywords: Cultural Heritage, Virtual Humans, Real-time Animation, Virtual Reality.

1 Introduction

The activities that participate in the protection of our common cultural heritage are not exclusively confined to the physical preservation of ancient sites against the threatening effects exerted by external hindering factors and agents, such as weather, climatic changes or the effects of the passing of time. Thus, we believe that the dissemination and promotion of pertinent information that might assist both the development of a better understanding of the contextualized social role that such places occupied in the ancient societies, and the scientific assistance that modern 3D visualization technologies might offer to further the comprehension of the historical hypothesis related to such sites, are essential contributors to the effort targeted at the strengthening of the protection of such heritage.

Consequently, in order to achieve a coherent and historically meaningful virtual visualization of any heritage site, it is crucial not only to proceed to the preparation of a valid and scientifically correct representation of the architectural qualities of the studied site, but it is equally essential to present the relations that existed between the physical site, its social function and the people used to live at the time in which it was still in use. In such respect, it is hence primordial to extend the traditionally conceived virtual heritage experiences with the inclusion of historically plausible virtual humans reenacting activities typically preformed in the time dependant context of the restituted site, thus adding a human dimension to otherwise sterile simulations devoid of any social consideration. In this presentation we will illustrate two case studies featuring the inhabited real time restitution of two heritage sites, visualized as they were during the Roman period, which exhibit the inclusion of contextualized staged storytelling scenarios in order to further the immersion of the user and promote a better understanding of the social function that such structures were occupying in their contemporary societies. The two case studies that will be employed to illustrate our general methodology are based on the results of the EU founded projects ERATO [ERATO 2006] and LIFEPLUS [LIFEPLUS 2005]. Since the ERATO project features a full VR simulation of the restituted elements and LIFEPLUS exhibits an AR setup for an on site experience, though these projects we thus demonstrate a different technological implementation of the same common methodological approach that happen to be both the backbone of our virtual heritage application creation pipeline and the main topic of this presentation.

1.1 Overview

After a brief introduction on the general subject of the article and a quick overview of the previous work related to the specific topic covered by our presentation, we will detail the data gathering process, which constitute the fundamental reference to achieve a successful and scientifically valid virtual restitution, that has been carried out in the first stages of the development of our presented case studies (section 2). Thus, we will present the collected material and the historical sources that were employed to assist the 3D modeling, mesh creation and texturing processes applied to define the appearance of all the elements constituting the virtually restituted 3D models of the considered archeological sites (section 3) and of the virtual humans inhabiting such spaces (section 4). In section 5, we illustrate the techniques and methodology associated with the preparation of the interactive elements which participate in the 3D real-time virtual reenactment of the activities performed by the animated virtual humans, such as body motion, facial animation, sound, music and scenario based interaction. The specific implementation in a VR or AR setup of the prepared elements is then discussed in section 6, where the specificities, advantages and drawbacks of either approach are presented. Finally, in section 7, we present the results of our VR-AR simulations accompanied by some final remarks and considerations on the performances of both setups.
and on the future work that might be required to further enhance such experiences (section 8).

1.2 Previous work

A Virtual and Augmented Reality-based heritage experience shall ideally give to the visitor the opportunity to feel that they are present at significant places and times in the past, stimulating a variety of senses in order to allow the experiencing of what it would have felt like to be there. However, a review of the range of projects described as Virtual Heritage [VHN 2004] [Kim et al. 2001] [De Leon et al. 2000] [Ley et al. 2001] [Papagiannakis et al. 2001] shows numerous examples of virtual reconstructions, virtual museums, virtual tours, and immersive virtual reality systems built as reconstructions of historic sites but sterile and devoid, or with limited inclusion, of any life forms. Engaging characters that are needed in an interactive experience are now slowly coming into focus with recent EU funded IST projects [Foni et al. 2002]. The main reason for their slow adoption is due to a) the incapability of current VR-AR rendering technology for realistic, entertaining, interactive and engaging synthetic characters and b) lack of interesting interaction paradigms for character-based installations c) lack of effective frameworks for multidisciplinary synergies and common understanding between historians, architects, archaeologists and computer scientists. In this article we attempt to address such issues through the presentation of a complete methodology that has been applied to recreate 3D interactive real-time virtual and augmented reality simulations with the inclusion of realistic animated virtual human actors exhibiting personality, emotion, body and speech simulations, and re-enacting staged storytelling scenarios. Although initially targeted at Cultural Heritage Sites, the illustrated methodology is by no means exclusively limited to such subjects, but can be extended to encompass other types of applications. Hence, we stress that with the assistance of a modern real-time VR-AR framework suited for the simulation and visualization of interactive animated believable and compelling virtual characters, such virtual experiences can be significantly enhanced and that the presented content might greatly benefit from the inclusion of a dramatic tension and with the implementation of a scenario based interaction. The abandonment of the traditional concepts usually associated with the simulation of static virtual worlds, which mainly feature limited interaction and simplified event representations, for the adoption of an interactive historically coherent character-based event representation is the prime subject and main concern of this presentation.

2 Historical and archeological sources

In order to succeed a scientifically valid virtual restitution of a given heritage site, one of the most critical aspects of the preliminary data collection phase is the gathering of pertinent and reliable historical sources both concerning the studied edifices and the social aspects structuring the daily life of the people that used to live at such times. Since in archeology related virtual reconstruction projects the amount of available architectural data is often limited, due to the fact that parts of the concerned structures are often now missing, it is therefore necessary to proceed to the formulation of restitution hypothesis in order to constitute a complete restitution of the structural and visual qualities of the sites targeted by the 3D visualization attempts. Consequently, a close collaboration with external advisors providing pertinent expertise, combined with the use of modern 3D visualization tools and technologies as a mean to test, study and validate specific structural hypothesis, is an essential requirement to achieve a coherent representation of the simulated sites. In this section we will briefly introduce some historical data concerning the two sites constituting our case studies and we will present the different sources that were employed as a base for the realization of our VR and AR real time simulations.

2.1 The Theatre of Aspendos

The theatre of Aspendos (Figure 1) is the best preserved roman theatre in Asia Minor, and it is calculated that it was built around 161-180 A.D. during the reign of emperor Marcus Aurelius. Certain remains in the theatre of Aspendos and oral sources imply that the theatre was used as a caravanserai (Merchants’ Inn) when in 1078, Pamphylia was claimed by the Seljuk Turks. In 1392 ottoman reign sat in and, by the declaration of the Republic of Turkey in 1923, Aspendos took its place within the boarders of the Turkish province of Antalya.

![Figure 1. The Aspendos Theatre in Antalya.](image)

It was only after the rediscovery of the theatre by European archaeologists in the 19th century, that an architectural evaluation of the structure became an issue and that the building caught the attention of scientists such as Lanckoronski [Lanckoronski 1892] and Texier [Texier 1862].

2.2 Lucius Placidus Thermopolium in Pompeii

The ancient city of Pompeii, which is located in western Italy in the Campania region near Naples, is one of the world’s best known Roman archaeological sites. Its notoriety comes both from the tales related to its spectacular and terrible destruction and from the extraordinary conservation state of its remaining, both consequential to Mount Vesuvius devastating eruption that happened the 24th of august 79 AD. The Thermopolium building that has been chosen for the on-site AR simulation experiment in the frame of the LIFEPLUS project (Figure 2) is one of the better preserved and most decorated taverns still existing at the Pompeii’s site.

![Figure 2. Lucius Vetutius Placidus Thermopolium in Pompeii.](image)
According to the inscriptions painted on the front of the building and the *tituli picti* of the amphorae found in the garden, it has been established that the name of the shopkeeper of the Thermopolium, and also owner of the adjacent communicating house, was a certain Lucius Vetutius Placidus.

### 2.3 Sources employed to restitute the sites

In order to restitute an accurate representation of the studied sites in their historically time-dependant context, several sources were used to assist and support the virtual reconstruction effort. The employed base material extends from architectural plans and sections used as reference for the 3D reconstruction of the edifices, to detailed topographical and geological data to represent at a larger scale the environment in which the sites are located, to hand drawn archeological restitution studies (samples shown in Figure 3) to assist the formulation of solid hypothesis regarding the visualization of the missing structural elements that were present in the past and are now lost. However, in the case of large sites, the necessity to widen and cross-check the gathered paper-based architectural and archeological data arises from the fact that such documentations generally exhibit precision related issues caused their large scale factor.

![Figure 3. Architectural plan (left) and hand drawn restitution (right) of the Aspendos Theatre Building [Lanckoronski 1892](Image 3)](Image 3)

Thus, on-site surveys of the studied sites have been conducted to collect complementary measurements and high-definition digital video and photographic data to be used as reference and support for the 3D modeling phase and as a base for the extraction and digital restoration of the diffuse textures to be applied to the modeled surfaces of the restituted buildings. Finally, where no pertinent data whatsoever could be found on specific missing structural elements, such as it is the case, for instance, for the statues located on the main scene building of the Aspendos theatre, after having sought external assessment and archeological advice, comparable elements still existing on similar sites, which are exhibiting historically consistent qualities in relation to the ones targeted by our visualization attempts, have been used as main references to complete our 3D virtual restitutions.

### 2.4 Sources used to create historically coherent virtual humans

To achieve a convincing virtual representation of the visual appearance and social behaviors that people were exhibiting during a past historical period, it is necessary to consider the different societal and functional aspects that were defining their daily life. Such elements may range from the identification of specific codified social conducts, rules, or particular dress codes, such as the ones that could be related to their clothing or hairstyling culture and practices (samples shown in Figure 4), to the creation of virtual models and animated scenarios that correctly represent the daily habits that were typical of the studied site at a given historical period. Hence, a highly interdisciplinary approach has been deployed in order to gather all the significant data required to fully cover the extent of the information necessary to succeed a historically coherent 3D restitution of the virtually inhabited heritage sites targeted by our case studies.

![Figure 4. Roman hairstyles and outfits of the 2nd century](Image 4)

Thus, in order to assist the data collection process whilst referring wherever possible to any accessible pertinent written or visual data available in literature, published studies or public museums, such as drawings, sketches, frescos, engravings, iconographic or photographic material, further complementary external historical, archeological and sociological expertise has equally been sought.

### 3 3D geometrical virtual restitutio of the sites

The main technical challenge that the presented case studies propose is to achieve a historically plausible and a visually pleasing representation of the appearance of the concerned sites in a 3D interactive real time environment, whilst maintaining a sufficient degree of geometrical precision to ensure a faithful and scientific valid restitution of the architectural qualities of the studied heritage items. Since the amount of geometrical detail, and thus the total number of polygons that can be used to render the geometrical complexity of a give model, ought to consider the available hardware limitations of the hosting platforms and the inherent constraints of any real time application, a careful preparation and optimization of the modeled 3D meshes is necessary in order to ensure real time animation and interaction capabilities to the final simulation. Consequently, it is of prime importance to find a suitable compromise in the trade-off that exists between precision, performances and visual impact of the simulations, in order to guarantee an optimum balance in all the elements that participate in the virtual restitutions. Hence, memory overload related issues or performance drops due to an excessive weight of either the loaded files or the visualized models need to be equally considered during the modeling phases of either the static buildings and the virtual humans, as well as during the texturing, material definition, illumination and animation stages. In this section we will thus illustrate such concerns trough the presentation of the modeling, texturing and illumination strategies that have been applied to our case studies. More specifically, we will exemplify such design choices with the presentation of a few examples pertaining to the Aspendos theatre simulation. Although the implemented methodology extends to both case studies, the Aspendos heritage site better illustrates our approach since it presents an extreme geometrical complexity and a notable amount of architectural detail that requires a more pronounced and extended application of such strategies.

### 3.1 3D model of the external environments

In order to model the Aspendos site virtual environment, namely the hill upon which the Theatre is built and its immediate surroundings, accurate topographic data was provided in the form
of a 2D elevation map of the area featuring elevation lines every 1 meter. Since this raw data alone does not allow a straightforward creation of an accurate textured 3D mesh of the terrain, the following methodology has been implemented in order to produce the final 3D model of the virtual environment. In a first stage of the pipeline the elevation lines present on the topographic map of the area have been isolated from the other depicted structures, like, for instance, roads and buildings, and have been imported as a sole block from the provided CAD file into 3D Studio MAX software package. Then the imported splines have been separated, regrouped and finally placed in the 3D space by their height relative to the lowest elevation line. The repositioned splines were then used as a base to build a high polygon 3D mesh (80,000 polygons) from which a grayscale elevation map has been extracted to be used to procedurally generate the diffuse textures. In order to meet the needs of a real time simulation, a simplified version of the 3D model of the terrain (4,500 polygons) has been prepared through automatic optimization and manual refining to be mapped with the previously prepared procedural texture (Figure 5 top).

Moreover, in order to further enhance to overall visual quality of the textures assigned to the terrain surface, in a latter stage of the project the procedural texture applied to the terrain has been replaced by a texture map derived from the composition of several satellite images to produce a representation of the modern site. Such images have been subsequently color corrected and shaded with an occlusion map to be used as a base to recreate an illumination baked terrain texture for the Roman environment with the elimination of all the modern elements (Figure 5 bottom). To further increase the visual impact of the restituted environment, the addition of trees and vegetation has been included with the implementation of billboard techniques as illustrated in figure 6.

Such billboards, representing a total of more than 30 different types of trees, have been prepared using as starting point real images of trees and bushes that have been edited to isolate their shape from their original background, and to add an alpha channel to allow their visualization with transparency effects.

### 3.2 Modeling and texturing of the buildings

For the realization of the 3D model of the Aspendos site, polygonal modelling techniques were preferred. Critical parts of the model, such as the Cavea, due to its extremely complex geometrical features, were given special attention to keep an acceptable trade-off between visual accuracy and the performance of the real time simulation. Moreover, wherever possible, the model’s surfaces were defined as single sided objects in order not to burden the final meshes with an excessive amount of hidden polygons. Furthermore, in order not to compromise the speed of the simulation, due to an overload caused by an excessively dense mesh, all the carved decorations of the stage building are rendered with the use of textures, since their geometrical features are negligible compared to the scale of the building and the scope of the simulation (samples shown in Figure 7).

In order to create the texture tiles to be mapped on the 3D geometry of the restituted theatre, the creation of a library of the main identified diffuse material textures present on the site has been made using as a base the on-site taken high resolution digital photographs: 150 different colour corrected textures that can be tiled seamlessly on the objects of the 3D scene have therefore been prepared and assigned to the model’s surfaces. However, unlike the process applied in [Foni et al. 2002], for the Aspendos site virtual restoration was not considered: the edifice features in fact little, or none, coloured decorative motives, and generally the surface materials consist of stone pattern variations.

### 3.3 Reconstruction hypothesis

In order to visualize the studied sites in their fully restituted state, i.e. to coherently simulate their architectural features whilst offering a plausible interpretation of the appearance they were exhibiting in the Roman times, it is necessary to carefully consider all the factors and all the possible reconstruction hypothesis concerning the elements that were present at that times and that are now no longer existing or available. In the case of the Aspendos site, for instance, elements such as the Velum covering the theatre, the roofing of the secondary buildings and all the decorative features of the main scene building, as well as a significant difference in the level of the ground, since part of the building is still buried, had to be pondered before proceeding to the constitution of the final 3D model of the site. The preparation of the 3D model of the Velum covering the theatre thus required special attention during the modelling phase: in fact, two contradicting sources were available (as illustrated by Figure 8), namely the restitution plans by Izenour [Izenour 1992] and the
ones by de Bernardi [de Bernardi 1970]. Hence, to define a plausible virtual restitution, the hypothesis presented by Izenour was kept as reference because his assumption, based upon a parallel with the Rome Coliseum Velum, succeeds in explaining all the ropes attach points still existing at the exterior of the theatre. After having sought external archeological and historical expertise, a modified version of Izenour interpretation has finally been implemented in order to address a further issue concerning the positioning of the lateral sections of the Velum: such hypothesis would have in fact implied a practical impossibility to operate the moving ropes used to open and close such sections from the roof of the secondary buildings.

Moreover, the formulation of a suitable restitution hypothesis concerning the roof of the side structures of the theatre, arising from the presence of a height discrepancy in the available restitution studies between such structures and the adjacent Cueva roof, has been equally addressed with the creation of a test set of more than 12 different 3D virtual reconstructions illustrating the more plausible and viable hypothesis.

Through direct experimentation and inspection of the 3D models, a subset of propositions deemed as the more likely from the structural and practical point of view have been compared to restrict the final choice to a only a few possibilities (samples from the test set shown in Figure 9). Subsequently, the chosen propositions have been presented to external advisors and thus a final version for the 3D restitution of such structural element of the theatre has been implemented.

3.4 Illumination strategies

To further enhance the visual impact of the real time simulation of the concerned sites, the addition of diffuse and hard shadows cast by the sun plays a central role. At an earlier stage of the virtual restitutions a full texture baking approach of a pre-computed radiosity solution has therefore been used. This approach however implies the creation of one texture per object: the bigger is the object, the higher the resolution of the generated texture has to be in order to avoid visual discontinuities, hence the risk to overload the video memory, either with excessively high resolution textures or by too many generated textures, is addressed. To overcome these restrictions the adoption of a light-map and diffuse-map real time multi-texturing approach has been adopted due to the fact that the diffuse textures can be tiled, and thus their resolution becomes independent from the size of the object upon which they are mapped, secondly the light maps can be downsized to very low resolutions without compromising the overall visual impact of the simulation, therefore eliminating the video memory overload issue. In order to visually simulate a more convincing virtual illumination of the Aspendos site, the use of High Dynamic Range Image Based Lighting has been implemented.

However, since the Aspendos virtual model had to be simulated under specific lighting conditions and at specific dates and hours of the day, the use of virtually generated light probes, allowing an arbitrary positioning of the direct sunlight, by means of parameters such as location, date and time, has been implemented to compute a global illumination solution for the creation of the lightmaps to be used for the real time simulation (Figure 10). Such approach allows, in fact, the dissociation of the lighting information from the material textures, and consequently allows for an overall better visual quality of the real time rendered surfaces and a reduction of the total weight of all the textures loaded into memory to perform the simulation (Results shown in Figure 11).

4 3D Virtual Actors

The range of relevant dimensions that ought to be considered while attempting to constitute a comprehensive virtual restitution of an archaeological or historical site it is not exclusively limited to the representation of its mere physical structure, but shall includes as well its social and local historical aspects. Thus, the addition of historically consistent virtual humans into virtual cultural heritage reconstructions both allows for a better understanding of the use of the architectural structures present on the site, and permits the creation of more realistic simulations of such ancient spaces with the inclusion of specific ambiances, atmospheres or dramatic elements. Hence, in order to both
4.1 Geometrical modeling of the actor’s 3D meshes

In order to create the animated virtual humans, the definition of the 3D meshes and the design of the skin surfaces of their body models have been conducted employing automatic generation methods, using real world measurement data, coupled with manual editing and refining. The main approach that was implemented in our case studies utilizes an in-house system based on examples [Seo et al. 2003]. The benefits of such method are threefold: first, the resolutions of the generated models are adapted for real time animation purposes; second, different bodies can be generated easily and rapidly modifying the base parameters of the template models (basic setup presented in Figure 12); third, since the implemented system uses real world data as reference by conforming a template model onto a scanned model, the generated meshes visually provide realistic results. The main assumption underlying such methodology is that any body geometry can be either obtained or approximated by deforming a template model. In order to succeed the necessary fitting process, a number of existing methods, such as [Digimation], could be used effectively. However, the basic idea that has been adopted in the present case is based on a feature based approach, as presented in [Seo et al. 2003], where a set of pre-selected landmarks and feature points is used to measure the fitting accuracy and guide the automatic conformation.

4.2 Creation of the 3D garments

To re-create the visual appearance exhibited by ancient clothes, source data such as frescos, mosaics and statues, coupled with written descriptions and complementary historical information concerning the garments, fabrics, colors and accessories has been used as a base to dress the virtual humans (Figure 14). The virtual garment assembly is executed using an in-house platform that employs general mechanical and collision detection schemes to allow the rapid 3D virtual prototyping of multiple interacting garments [Volino et al. 2005, 1 and 2][Volino et al. 2006, 1][Magnenat-Thalmann et al. 2002].

The implemented system integrates the design of 2D patterns, the geometrical representation of an entire garment suited for real-time animation purposes requires several stages. First, the creation of the basic patterns constituting the main elements of the garment is made in a 2D space employing as modeling reference the silhouette of the target 3d body. Second, the obtained patterns are placed around the target virtual body and seamed in a 3D space.
Third, once the texturing and garment physical properties definition phases are complete, the interactive fitting process of the virtual garment is started employing a mechanical simulation featuring advanced collision detection and reparation capabilities [Volino et al. 2006, 2] (Figure 15) which forces the modeled surfaces to approach along the seam lines and to deform according to the 3D shape of the underlying body. The final position displayed by the dressed virtual human after the completion of the simulation process constitutes then a suitable starting point to apply any animation file, such as motion capture data, in order to calculate the animation key-frames for the simulated cloth.

4.3 Virtual Human’s accessories

Since the activities reenacted by the virtual humans in the selected case studies were requiring the inclusion of various auxiliary objects in the virtual environments, the preparation of 3D models of the required accessories has been carried out. Among the additional 3D object we may cite the ones that are manipulated by the virtual characters, as for instance some utensils such as the amphorae in the Thermopolium simulation or the musical instruments in the Aspendos simulation, or the ones that represent constitutive elements of the outfits of the simulated virtual humans, such as the masks of the virtual actors performing in the virtual Aspendos restitution. Thus, historical data, such as engravings and frescoes, as well as iconographic and photographic material (Figure 16), such as [Monaghan 2001] has been used to support to completion of the 3D polygonal models of the considered accessories.

Figure 16. Roman theatre actor’s outfits [Monaghan 2001]

While the modeling of the basic accessories, such as for instance the masks and props of the Aspendos virtual actors, required considerable attention and an in-depth research to define a plausible representation of their restituted appearance, real world references, built in the frame of an experimental archeology experience carried out by the musicology department of YTU, were employed to create the 3D meshes of the ancient musical instruments to be included in the simulation. The finished 3D models of the instruments, masks and accessories participating in the simulations (Figure 17), have then been linked to the bodies of the 3D virtual humans to allow their manipulation during the real time animation by the virtual characters and their role has been associated to specific scripted actions and behaviors.

Consequently, these objects have been connected to the skeleton of the virtual humans, and their position and orientation have been adjusted according to their movements. To ensure a maximum accuracy in the postures and animations reproduced by the virtual humans while interacting with such accessories, world scale representations of such elements, featuring comparable weight and size, were used during the motion capture sessions to mimic the effect they might exert on the recorded actions.

5 3D interactive real-time virtual visualization of ancient inhabited places

The case studies described in this paper presents the inclusion of real time animated virtual humans that are re-enacting situations and activities that were typically performed in roman sites during ancient times. The simulated scenes are composed by different elements, both visual and non-visual, such as the 3D models of the actors, the 3D environment, sounds, music, voices and behavioral rules. In order to assist the creation of such complex scenarios, which involve different actions and require a precise control of the simulation events, a scripting language has been implemented to handle and drive the interactions between all the elements participating in the simulations. Hence, for each particular scenario, a dedicated system configuration data file specifying the necessary system parameters, the required physical environment parameters and the parameters concerning the VR and AR devices used to output the visual results, has been prepared to control the simulations. Moreover, several scripts have equally been prepared in order to define and in detail the atomic behavior of complex elements, such as the actions to be performed by the animated virtual humans.

5.1 Activities reenacted by the virtual humans in the selected case studies

Five different scenario driven simulations have been prepared for the two case studies: two scenarios describing daily life situations in Pompeii, respectively taking place in the Thermopolium of Vetutius Placidus and in a garden of a villa located nearby, and three excerpts form Greeks dramas to be reenacted in the virtually restituted Theatre of Aspendos, including the Agamemnon of Aeschylus, the Antigone of Sophocles and a choral song from the Iliad. Although the implemented approach extends to both case studies, we will detail in this section the scenario prepared for the Thermopolium site in Pompeii, since it involves several interactions between many virtual actors at the same time thus requiring an increased complexity in the scripts driving the simulation.

Taverns were common and characteristic social gathering places in the ancient Pompeii. They were public establishments where hot food and drinks were served, and where many people used to meet in order to eat, drink, play or simply talk. As introduced beforehand, the Thermopolium of Vetutius Placidus, located half a way in Via dell’Abbondanza, has been chosen for the realization of an AR real time simulation. The structure of the considered building is simple and typical of the Roman period, and is one of the best preserved on the archeological site, since most of its original furniture was found during site’s excavation. The preparation of the main scenario has been entrusted to a professional team of screenwriters assisted by archaeologists and specialists in Ancient Pompeian life whose role was to supervise and guide the process, thus ensuring that the final result would have been historically valid. Hence, the final implemented scenario has been structured as taking place inside the tavern main entrance room, whilst including acoustical clues and additional background noises suggesting the presence of several other people.
in the adjacent rooms. Secondly, the virtual characters performing the simulation were defined as acting as they normally would have in a real tavern and as exhibiting historically consistent outfits in order to mimic and virtually recreate specific scenes that can still be observed on the frescos on-site and reproduce dialogues taken from inscriptions found there.

In order to succeed the transposition of the scripted scenario into the virtual simulation and to assist the character modeling and animation phases, several references to real world examples were employed. To support the creation of the virtual dresses, for instance, and to provide tangible physical references for their simulation, real prototype counterparts were designed, tested and commissioned to a tailor using the available historical data. Moreover, to assist the motion capturing sessions, and to provide the character animators with solid visual references and clear guidelines to prepare and time the actions performed by the virtual humans, all the events and dialogues of the scenario have been filmed and recorded while being reenacted by professional actors (Figure 18).

5.2 Animating the Virtual actors

To create the animation files to be applied to the virtual humans, a VICON Optical Motion Capture system based on markers [Oxford Metrics 2001] has been used (Figure 19). As previously introduced, in order to assist such process, several video references where employed as support for the motion capturing sessions: in both case studies digitally recorded video sequences featuring real actors playing the scenarios to be virtually reproduced have been prepared with the assistance of the historical advisors.

Hence, a projector has been used to screen the real actor’s performances in order to provide the motion captured subject with an appropriate reference to time his movements and synchronize his actions with the recorded sounds and dialogues. After the completion of a post-processing phase, the captured movements that correspond to the various parts of the scenarios to be reenacted have been converted to separate keyframed animations ready to be applied to our H-Anim skeleton hierarchy compliant virtual characters (Figure 20). Since the final animation resulting from the application of motion captured data generally exhibits a realistic motion behavior but a limited flexibility, in our case studies the different recorded tracks have been connected to each other to produce complex smooth sequences featuring no interruption during their execution. To this end, a specialized blending engine that can blend several different types of motions, including real-time idle motions and key-frame animations [Egges et al. 2004], has been implemented as a service into our in-house VR-AR framework [Ponder et al. 2003] to control both face and body animation [Egges et al. 2005]. Consequently, for each virtual human loaded into a given scene, an XML file containing the description of all the actions and animation files that need to be available for playback during the real time simulation, and including the specific configuration of the parameters that drive the blending engine, has been prepared.

Thus, an Animation Property that contains a blending schedule allowing the definition of some specific options, such as whether or not facial and/or body animation should be played or if the translation/orientation of the virtual character should be considered as defined on the global or local coordinate system, has been defined for each 3D virtual human participating in the real time simulation. Finally, the implemented service also includes an integrated player that plays and blends in real time the scheduled animations in a separate thread for all the humans in the scene during the 3D simulation [Papagiannakis et al. 2006].

5.3 Integration of sound and music

To further the user’s immersion, and to enhance the overall believability of the simulated restituted inhabited places featuring reenacted scenario based events performed by animated 3D virtual humans, the inclusion of sounds, voices and musical elements constitutes a fundamental contribution to achieve a convincing interactive virtual experience. In the frame of our case studies, different strategies have been implemented depending on the type, precision and final scope of the simulated sound sources. In such respect we can therefore consider as separate cases the voices of the virtual actors, requiring an accurate synchronization with their movements, a proper spatial positioning and a suitable acoustical intelligibility, the background noises and any undistinguished sound produced outside the direct focus of the simulation, and finally any accompanying music serving dramatic or narrative purposes. Due to the fact that in the presented case studies the implementation of the background noises and the accompanying music has been mostly a straightforward process, therefore not requiring the deployment of any particular or specific technique or technology, we will focus on the first case constituted by the rendering of the actor’s voices. Since the restituted virtual actors shall embody people that used to live at a specific site during a given historical period, the choice of the language to be used for the preparation of the sound files to be played during the final simulation ought to be pondered. While it
might be considered as an acceptable compromise to actually simulate the spoken interactions incurring between the different virtual humans using a modern spoken language, such as for instance modern English, in the Aspendos simulation it was otherwise preferred to provide the simulated virtual humans with English captioned ancient Greek and Latin spoken lines. Such dialogues and lines have been hence prepared with the supervision of historical consultants and have been recorded employing an anechoic chamber while being performed by real actors. Subsequent to the recording phase, using the geometrical model of the site and surface material data, the anechoic files have undergone an auralization process [Lisa 2004] in order to create the facial animation and lip-sync effects.

In the real time simulation such generated files have been linked to interactive area triggers, thus allowing the user to accurately perceive and experience the simulated voices from specific positions in the restituted virtual site exactly as he would have on the real one, while preserving his capability to freely explore in real time the simulated 3D virtual model. Finally, the prerecorded sounds have been manipulated in a Python scripting environment to constitute the final scenario, which details the temporal concatenation of the sound files, and have been used as reference to create the facial animation and lip-sync effects applied to the 3D real time virtual humans.

6 Real time Implementation

In order to proceed with the rapid development of such demanding high performance interactive immersive VR and AR applications, featuring advanced virtual human simulation technologies and advanced lighting effects, we adopted the VHD++ real-time framework (overview depicted in Figure 21), as described in [Ponder 2003], which addresses the most common problems related to the development, extension and integration of heterogeneous simulation technologies under a single system roof while combining both framework (complexity curbing) and component (complexity hiding) based software engineering methodologies.

As a result, a large scale architecture and code reuse has been achieved which has allowed to radically increase the development efficiency and robustness of the final VR and AR applications targeting the virtually restituted archeological sites of Aspendos and Pompeii. The Aspendos simulation features a complete VR inhabited interactive reconstruction of the archeological site using as input devices a standard keyboard and a mouse while displaying the results of the simulation employing a stereo projector on a polarized screen, thus enabling the user with a 3D perception of the simulated space. While the Aspendos simulation features and extremely complex geometry and a huge polygonal model to be animated in real time, the Pompeii AR application exhibits a simpler scene which however requires real time markerless camera tracking [Lourakis 2003][2D3 2006] and perspective registration capabilities on a mobile setup [LIFEPLUS 2005][Papagiannakis et al. 2005], in order to allow the user to experience on-site the restituted augmentations of the real space through an HMD. Finally, in order to manage the simulation events on both the VR and AR setups, the implemented software architecture allows the control of the interactive scenario states through the selective application of Python scripts at run-time. Such mechanism therefore offers the ability to interactively and efficiently describe complex sequences of timed events and articulated scenarios as simple scripts which can control all the different elements participating in the real time simulations. Furthermore, such approach enables the user to modify in real-time any data in use by the current simulation, such as the behaviors of the digital actors or the position and animation of the virtual cameras, therefore allowing the simulation to continue running whilst modifications are performed.

7 Results

The basic scenegraph OpenGL renderer that has been implemented in our VHD++ framework provides both advanced particle system simulation and occlusion and view frustum culling that have been both successfully integrated and tested in the ERATO and LIFEPLUS platforms. The aggressive view frustum culling allows the final scene of Aspendos site, featuring a model constituted by more than 300,000 polygons, and requiring 1GB of total textures size, to be rendered on a stereo projector at ~20fps, according to the view frustum and part of the visible scene within the virtual camera frustum. Such scene includes the full 3D model of the Aspendos theatre, featuring radiosity processed lightmaps applied at material level to simulate global illumination trough a multi-texturing approach, and 3D real time virtual actors illuminated through PRT (precomputed radiance transfer) [Papagiannakis et al. 2005]. Regarding the reconstructed theatre, offline light-mapping rendering methods have been utilized in order to allow the viewing of the theatre under the static area light created using the Aspendos virtual Light probe. The main reason for the implementation of a static lightmap solution was the fact that the reconstructed model exhibited a very high polygonal count and a high number of required texture memory, thus making any real-time algorithm difficult to apply. Figure 22 illustrates a final example featuring 3D Virtual Humans rendered via our extended precomputed radiance transfer algorithm for illumination registration [Egges et al. 2006] in the virtual inhabited world of the Aspendos site, employing the same area light used to statically illuminate the mesh of the theatre of Aspendos. Finally the virtual actors and their clothes were modeled based on the work described in [Magennat-Thalmann et al. 2004]. The verses are spoken in ancient Greek and the excerpt has been chosen from the tragedy “Antigone” of Sophocles.

Figure 21. VHD++ MR Framework Overview

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Figure 22. Screenshots from the final VR simulation of the inhabited Theatre of Aspendos featuring real time illumination through PRT and lightmaps (right) vs a simulation of the same site using standard illumination methods only (left).
To meet the hardware requirements for the Pompeii AR simulation, a single P4 3.20 GHz Mobile Workstation with a GeForce FX5600Go NVIDIA graphics card and an IEEE1394 Unibrain Camera [Unibrain 2006], for fast image acquisition in a video-see-through i-glasses SVGAPro [I-Glasses 2006] monoscopic HMD setup, were used to create the basic setup for an advanced immersive simulation. Our AR-VR framework applied to the final Thermopolium AR restitution, featuring 5 fully simulated virtual humans, 20 smart interactive objects, 1 python script and 1 occluder geometry, allows the simulation to run at 20fps for the camera tracker and 17fps for the main MR simulation in a controlled environment and at 13fps and 12 fps respectively during the on-site trial. Results are depicted in Figure 23.

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**Figure 23. AR Setup used on-site for the real time simulation (top), virtual scene calculated by the computer (bottom left), real environment augmented with virtual elements as seen through the HMD (bottom right).**

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### 8 Conclusion and future work

Through the application of the same basic methodology presented in this article, we were able to prepare all the necessary elements participating in both our case studies and we succeeded in achieving real-time interaction capabilities with the support of our VR-AR framework, which is able to manage indistinctly real-time virtual and augmented reality full character simulations exhibiting body, face and clothes animation in digitally restituted complex cultural heritage environments.

However, there is still a lot of room for improvement, specifically concerning the illumination registration method which employs real light on the virtual scene. Currently certain issues regarding this particular point have been addressed with the introduction of High Dynamic Range Image Based Lighting for virtual character simulations [Papagiannakis et al. 2004], combined with Dynamic Precomputed Radiance Transfer, to yield real-time results featuring Global Illumination effects. Nevertheless, mainly due to current hardware limitations, such method does not yet allow the simultaneous inclusion in the simulated environments of more than three fully animated and lighted virtual characters without causing noticeable performance drops in the frame rate. Therefore, optimizing the rendering speed and the overall performance of the simulations, whilst keeping such complex illumination effects and extending of the maximum number of high fidelity virtual humans included in the real time environments, will be one of our priorities for further development. Secondly, we will seek to complete the array of the features exhibited by our simulated virtual humans with the inclusion of real time hair simulation, dynamic level-of-detail, to improve their realism and overall rendering performance, and advanced interaction capabilities with the user, including voice recognition and speech synthesis. As a concluding remark we would like to stress that any virtual restitution targeting highly complex heritage sites inherently requires accurate choices for each phase of the modeling, texturing, lighting and implementation processes, and special attention must be always used when the models have to be prepared for a real-time simulation exhibiting the inclusion of animated virtual historical characters. Furthermore precise and reliable source data is critical to achieve scientifically correct and accurate restitutions. Finally, we would like to mention as well that performing interpretative and comparative studies is also a necessary step when the intended restitutions are targeting lost architectural elements of the considered heritage sites. Therefore, modern 3D visualization technologies could be employed to perform virtual experimental archeology tests, thus offering new possibilities to validate, compare and explore in a 3D environment reconstruction theories and hypothesis.

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