



REENACT: A step forward in immersive learning about Human History by augmented reality, role playing and social networking[☆]



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ABSTRACT

Classical pedagogy about Human History has dealt with many historic events as a mere collection of dates, locations and a number of confronted sides with a final result of victory or defeat. In the same line of thinking, many popular battles and wars are not well understood due to non-rigorous treatment in comics, movies and documentaries. In order to fight these drawbacks we propose a novel technology-enhanced pedagogical approach named REENACT which is aimed at engaging groups of people into immersive experiences to improve their learning about historical battles and wars from the points of view of reenactors and historians. To this aim, REENACT relies on handheld devices and an advanced technological facility that comprises social networking features, augmented reality capabilities and repositories of multimedia contents. Our pedagogical approach has been experimentally validated in collaboration with the Foundation of the Hellenic World in Greece and the School of Telecommunication Engineering from the University of Vigo in Spain. The obtained results in terms of Quality of Experience, Quality of Service and Quality of Community reveal the potential value of the approach to provide new edutainment collective experiences which remain unexplored thus far in educational environments.

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1. Introduction

Human History includes a large number of battles and wars, whose results cannot be understood properly from the traditional teaching, where they are presented as occasional events that involve two sides (the good and the evil forces) and that apparently end fortuitously. Nothing is so simple in reality, and so the classical pedagogical approach neglects many facts about the reasons for the battles, alliances and supporters, why things went on the way they did, what were the winning or losing choices, what were the consequences in the short, medium and long terms, etc. As a result, our general awareness of History is rather partial and deficient, and students end up with little more than a collection of dates and a vague idea of who defeated who.

It is obvious that educational environments are scenarios where the promotion of debates and brainstorming should be a must.

The current technological context makes easier the development of novel approaches that boost the collaboration not only among students but also among them and the expert who leads the teaching about a particular topic/subject. Bearing these ideas in mind, we bet on taking the advantage of the emergence of novel technologies – such as smartphones and tablets, social networking, video-games for learning and even virtual reality – which pave the road to make things better and more interesting in teaching about historical events. Specifically, in this paper we present a new pedagogical proposal (called REENACT) that has been developed in the scope of a Seventh Framework Programme (FP7) research project named EXPERIMEDIA.¹ The REENACT approach exploits augmented reality (AR) technologies to improve the understanding of historical events with the aid of tactile mobile devices, repositories of multimedia contents, an advanced technological facility and remote experts (López-Nores et al., 2013). REENACT has been designed as a Future Media Internet application to engage groups of people into immersive learning experiences, to learn more about the reasons behind a particular battle or war, the course and the result of these historical events.

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¹ www.experimedia.eu.

Our pedagogical methodology over REENACT is organized in three stages, where participants can live the event learning about it from inside as reenactors, and also from outside, as historians. Actually, REENACT is not a multiplayer online game but a collective in-person activity supported by handheld devices.

- Stage 1 (*reenactment*) is about involving groups of people in the reenactment of battles. They can physically move around in a room, playing the actions defined for a given role by a script of the particular historic event and interacting with the other participants inside the game. Tactile mobile devices provide the participants with an augmented reality vision resembling a multiplayer role-playing game. In this stage, the participants can spend some time in different designates zones (within the reenactment room), which correspond to real places relevant to the battle in question. While staying in a given zone, a participant can interact with other users as dictated by the reenactment script, e.g., to talk, to negotiate or vote on some decision, to fight, etc.
- In stage 2 (*replay*), the participants are taken to a projection room to analyze what has been happening. They have already lived the battle from inside, with a very partial vision, and now it is turn to learn more by watching things from outside, and to see how their recreation compares to the real historic events. The explanations are given by one expert, who may be physically present at the projection room or appearing on the screen from a remote location.
- Finally, in stage 3 (*debate*), the expert drives a collective brainstorming about the consequences of the conflict in the short, medium and long terms. The projection screen becomes a dynamic big board to display comments posted by the participants involved in the learning experience, which can be rearranged by the expert as the debate goes on. At any time, the expert can illustrate the different points that are raised by multimedia contents which will be automatically selected according to their relevance for the particular context.

The validation of our pedagogical proposal over REENACT was done in collaboration with two institutions: first, the Foundation of the Hellenic World (henceforth, FHW), a not-for-profit cultural institution in Athens that enjoys a unique technological infrastructure (including a dome-shaped virtual reality theatre named Tholos), and second, the School of Telecommunication Engineering at the University of Vigo. In both experiments, we dealt with the Battle of Thermopylae, a historic event where Greek city-states (led by King Leonidas of Sparta) and the Persian Empire of Xerxes I fought during three days at the narrow coastal pass of Thermopylae. This scenario is propitious for our validation purposes because the event is quite popular but it is not really well understood due to non-rigorous treatment in movies and comics, where the Battle of Thermopylae is presented as a fight where some handsome good Spartans were defeated by a huge number of abnormally-ugly bad Persians. Fortunately, the details reported by [Herodotus \(1922\)](#) and other historians provide sufficient scenes to yield both a didactic and enlightening experience to explain such facts as the advantages of training, equipment, and good use of terrain as force multipliers. Furthermore, the FHW had produced its own multimedia contents about the battle, which was invaluable material for the three stages of the REENACT experiences. We also enjoyed support from the FHW historians to develop historically rigorous reenactment scripts and to foster interesting debates.

This paper is organized as follows. In Section 2 we review related approaches to technology-driven learning experiences. Next, Sections 3 and 4 describe the internals of the three stages that shape our pedagogical proposal and the implementation details behind the REENACT system, respectively. The experimental vali-

ation of our approach in collaboration with the FHW and the School of Telecommunication Engineering will be described in Section 5, where we also discuss the achieved results in terms of key performance indicators derived from *Quality of Experience* (QoE), *Quality of Service* (QoS) and *Quality of Community* (QoC) metrics. Finally, Section 6 highlights the main conclusions drawn by the authors from our first testing experiences, along with possible extensions to enhance the REENACT approach.

2. Related works

The use of certain technologies (like video games) in learning activities is not new at all ([Abt, 1970](#)), yet recently there has been a renewed interest in their adoption in order to motivate and stimulate higher order thinking when it comes to providing the students with improved instructional experiences ([Anagnostou, 2011](#); [Charsky & Ressler, 2011](#); [Fassbender, Richards, Bilgin, Thompson, & Heiden, 2012](#)). In the line of these samples of new educational approaches, we can highlight the work presented in [Akkerman, Admiraal, and Huizenga \(2009\)](#), where Akkerman et al. analyze a mobile game (called *Frequentie 1550*) which includes a one-day activity meant for secondary school students to actively experience the History of the city of Amsterdam in late medieval era. Before starting the game, the students were introduced into the main story line of the game, its parts, tasks and tools to be used. Next, the users were organized in groups of four or five people. Each group was divided into a *city team* and a *head quarter team*, so that the students of the first one moved around the city experiencing buildings, receiving messages and instructions from the head quarter team members, completing game assignments (e.g., taking pictures or shooting videos), while using mobile phones for communication and exchanging information. The results derived from [Akkerman et al. \(2009\)](#) reveal different levels in the students' engagement as per their role in the game: the city team members actively participated in the game (living the story and experiencing it more deeply) but their focus was also distracted by what was happening in real time in the street. However, the head quarter members were aware of what they had been doing during the game, without losing the sight of its overall structure and its narrative. Extrapolating these results to our REENACT approach, we might think that the reenactors could lose the flow of the historic event due to their active involvement in the first stage of the experience (reenactment). However, we guess that the brainstorming driven by the expert (a role not considered in the game by Akkerman et al.) during the replay and debate stages will be crucial to trigger the participants' awareness of the historic event considered.

The adoption of educational video games has gained momentum especially in teaching about History. For instance, in [Watson, Mong, and Harris \(2011\)](#) assess the videogame *Making History* as a valuable tool in capturing the experience of a teacher and his students when it comes to teaching about the World War II in a high school. While students played the game, the teacher moved around the classroom answering to questions and posing his own, having a final discussion about the strategies the countries tried, how they differed from History, and what conclusions could be drawn. The results published in [Watson et al. \(2011\)](#) are concluding and common to other technology-enhanced learning experiences published in literature ([Chien, Wu, & Hsu, 2014](#); [Kim, Olfman, Ryan, & Eryilmaz, 2014](#); [Noteborn, Dailey-Hebert, Carbonell, & Gijssels, 2014](#)): the teacher noted the active participation within the classroom, and the students highlighted the edutainment potential of the game, which undoubtedly reinforces the adoption of technological capabilities in improved learning experiences about historic events like those handled in our REENACT approach.

The effects of the social networking boom have also been noticeable in the realm of History teaching. This way, some works in the state-of-the-art (Arends, Weingartner, Froschauer, Goldfarb, & Merkl, 2012; Trant, 2006; Trant & Wyman, 2009) explore social tagging and social networking sites as fruitful tools to (i) actively include the users in the creation process of meta-information – by annotating, for instance, artworks as per their knowledge and emotions, and (ii) share their semantic annotations with other individuals via sites like Facebook, Twitter or Google+. In REENACT we do not consider this kind of sites for metadata sharing, but our goal is to create a sporadic social network of users doing something together for some time where they can (i) share their particular perspective and acquired knowledge after the reenactment, and (ii) interact actively among them and with the expert who drives the brainstorming during the replay and debate stages. In contrast with existing works, our social networking features go beyond a way of informing the participants' (social) contacts about their involvement in the REENACT experiences. Actually, in our approach these social functionalities are the cornerstone of a rigorous and strict review driven by an expert in order to enable the participant to get a deeper understanding of the intricacies of the particular historic event considered.

There also exist works where virtual reality is exploited in improving learning experiences in several domains. For instance, in Juan, Llop, Abad, and Lluch (2010) the authors describe a game based on augmented reality for learning words in Spanish, where a virtual pet gives instructions to the children involved in the experience to play several games aimed at spelling, completing and looking for letters missing in a set of words. Also in the scope of virtual reality, note the approach by Jacobson et al. where the authors explore a virtual version of field trips as a pedagogic tool for courses about civilizations at the University (Jacobson, Militello, & Baveye, 2009). Specifically, these *virtual field trips* (VFT) involve maps, images and video clips in a variety of formats with the goal of helping students imagine what a real field trip to the site would be like. In view of the results in Jacobson et al. (2009), VFTs allow to (i) use media in the generation of a rich, exploratory, multi-modal experience that is not possible in a unidirectional presentation such as a text, and (ii) expose students to unfamiliar situations and places so that they would better understand the complexities involved and thus have the background to critically analyze the issues analyzed in the course.

The exploitation of immersive experiences and the adoption of technology have also gained momentum in multiple applications. For instance, in Liljenstam et al. (2006) resort to immersiveness in the development of RINSE, a *Real-time Immersive Network Simulation Environment* which deals with security attacks for training network administrators, and metrics to keep the network services operating. Likewise, other approaches have experienced with immersiveness in very diverse learning environments (Code, Clarke-Midura, Nick, & Dede, 2013; Kozhevnikov, Gurlitt, & Kozhevnikov, 2013; Nadolny, Woolfrey, Pierlott, & Kahn, 2013). Out of the academic realm, diverse technological capabilities have been tested when shaping the cultural offers publicized by museums, where people gather together to learn about a specific subject and to enjoy new personalized itineraries within the buildings through handheld devices (Falk, 2009; Fleck et al., 2002; Gerber et al., 2010; Kuflik, Kay, & Kummerfeld, 2010; Lykourantzou et al., 2013; Stock et al., 2007; Wang et al., 2009). The potential of these itineraries is due to the fact that they are created as per the particular preferences and interests of each visitant, thus providing a tailor-made edutainment experience. As we will describe in the results of our tests in the FHW in Greece, REENACT also exploits the technological capabilities of mobile devices in the scope of a cultural institution, however our purposes are quite different from those considered in the related approaches described

along this section. Basically, REENACT differs in (i) the provision of an enhanced learning environment with a wide number of technological capabilities that have not ever been experienced together so far – such as augmented reality, social networking, role playing games for making decisions on behalf of a particular (historic) character, among others, and (ii) the involvement of an expert who will actively interact to the participants to learn more together about the reasons, course and consequences of a historic event, from both the perspective of reenactors and the historians' point of view.

3. Our pedagogical proposal

In this section we detail the internals of the three stages included in our pedagogical methodology, by considering examples borrowed from the Battle of Thermopylae to describe how *reenactment*, *replay* and *debate* work in REENACT.

3.1. The reenactment stage

The REENACT experiences start out with a brief projection explaining the historical context of the battle. The roles, zones and the script of the battle we consider in our approach are detailed in Appendix A, where we describe four acts in the course of the battle considering even deviations from real happenings to promote debate and explanations by the expert. Then, the participants are *armed* with their tactile mobile devices and assume a given role in the battle, fighting for whichever side. Each participant chooses to be represented by a customisable avatar or by a close-up photograph.

The reenactors follow the actions and make the decisions allowed by the scripts of their respective roles, which make them move physically around in a room with a number of zones identified by markers on the floor or on the walls, which correspond to real places relevant to the battle in question. While staying in a given zone, a participant can interact with other users using the handheld device, as dictated by the reenactment script, e.g., to talk, to negotiate or vote on some decision, to fight (by shaking the devices as if they were swords or by dragging QR markers on the floor to engage in augmented-reality one-on-one combat), etc. As we will describe in Section 4, the implemented interfaces are highly intuitive to ensure the participants' comfort while using them.

Also, through the tactile mobile device, each participant visualises his/her position in the scenario of the battle, where the rest of the people are characterized as per their avatars and the roles they have assumed. Augmented reality technologies are used to enhance the immersion, e.g., by providing 360° views of Thermopylae from one side of the other or by linking 3D contents with the QR markers laid on the floor or on the walls. Additionally, the tactile mobile devices provide the participants with the actions they may make at any given moment: to advance on a certain stand, to retreat, to take some message to someone, to fight one way or another, to surrender or not, etc. The choice of possible actions is a function of each individual's choices, of the orders delivered by the respective commanders, of decisions made collectively by voting, and so on, as determined by the script of the battle. As described in Appendix A, if the character played by a user dies in the course of the battle, he/she is given the opportunity to pick up a new role in order to continue in the game.

To enhance the feeling of a collective experience, we can use any big screens or projection boards available in the reenactment space to display the visualization of the scenario of the battle, along with video footage that may serve to illustrate what is going on, and even pictures or textual comments coming from the reenactors' tactile mobile devices. If available, loudspeakers

can play accompaniment music and sound effects for further immersion.

3.2. The replay stage

Once the recreation of the battle has finished, the participants are taken to a projection room in the experimentation venue to analyze what has been happening. They have already lived the battle from inside, with a very partial vision, and now it is turn to sit down and learn more by watching things from outside, to see how their recreation compares to the real historic events.

The second stage of the REENACT experiences are driven by one expert, who may be physically present at the projection room or appearing on the screen from a remote location. The expert relies on a record of the movements and actions of each participant during the reenactment. Combining this record with the script of the battle, the expert can identify specific situations lived by the reenactors that could serve to explain important facts about the course of the fights (e.g., to illustrate the technological superiority of one of the opponents, the war tactics employed, etc.).

The expert's interfaces show a timeline of what each one of the participants has done, decided and watched during the reenactment stage. The sequence of contents displayed on the big screens of the reenactment space is displayed, too. This way, with the assistance of an automatic process that will be described in Section 4.2, the expert can choose the most suitable contents to support his/her explanations, which are also projected along with the video feed from the expert's webcam and some additional material, like a map of the battle with the avatars in place or textual comments typed by the reenactors.

The important point of the replay stage is to relate the reenactors' experiences with the historical facts, which should help them to realise and memorise facts that usually go unnoticed in traditional History teaching. Therefore, the expert can devote some time to explaining what aspects of the reenactment diverge from the real facts, either because the script makes some allowances or because the participants have made the opposite of the real characters' decisions. Exemplifying this line of thinking in the specific realm of the Battle of Thermopylae, there are a few facts worth mentioning about the Persian and Greek sides at the beginning of the replay stage:

- On the one hand, it must be explained that the Persians were certainly not the abnormally-ugly bad guys depicted in certain movies, but people from different places of Western Asia (Media, Parthia, Assyria, Armenia, etc.) that were ruled by the Achaemenid Persian Empire. Their expansionism had nothing really particular, since those ancient times saw tens of imperial aims and the options were only those of conquering or being conquered. Yet, the Achaemenids were known to respect the autonomy and the ways of life of the territories they conquered.
- On the other hand, the ancient Greeks are often surrounded by an idealistic halo that does not actually tell the whole story. To begin with, the different city-states were not friends to each other, since there were frequent battles between them. They did not even join all their forces to fight the Persians: some of them did, but others surrendered, were defeated or were abandoned to their fate by the others. Besides, even though Western culture praises the Greek's principles of freedom, democracy and the like, it is also true that slavery was institutionally recognized in many of the city-states.

To keep the replay as a playful experience too, we include quiz games to appraise the reenactors' understanding of the prelude and the course of the battle. In this regard, during the replay the expert can choose to run a collective quiz game with multiple-

choice questions. Our approach considers also qualifying games (where the one who misses an answer is eliminated) and cumulative ones (where the one who gets the greatest number of correct answers, wins). The questions will involve dates, people, historical context and any other features related directly to the Battle of Thermopylae. Typically, there will be only one correct answer, while at least one other option could make sense and at least one would be ridiculous (just to enhance the entertainment aspect). However, there may be questions in which all the answers are correct, just seeing the same fact from different perspectives. A few examples of questions and answers could be as follows:

- Question 1: What was the year of the Battle of Thermopylae?
 - (1) The 4th year of the 74th Olympiad according to the Attic calendar. (TRUE)
 - (2) Year 274 ab urbe condita. (TRUE)
 - (3) Year 2157/2217 according to the Chinese calendar. (TRUE)
 - (4) Year 23 according to the Achaemenid calendar. (TRUE)
- Question 2: Who was the predecessor of Xerxes I?
 - (1) Xerxes O. (FALSE)
 - (2) Darius the Great. (TRUE)
 - (3) Julius Caesar. (FALSE)
 - (4) Arnold the Great. (FALSE)
- Question 3: What type of bridge was built to cross the Hellespont?
 - (1) A pontoon bridge. (TRUE)
 - (2) A Roman stone bridge. (FALSE)
 - (3) A cast iron bridge. (FALSE)
 - (4) A suspension bridge. (FALSE)

As introduced before, the goal of the replay phase in REENACT is to provide the users with a common, global perspective by facing them with general interest questions and contents, which might not have been posed to each participant during the reenactment (depending on the role he/she was playing). For that reason, during the replay (and the debate), the expert does not handle only questions extracted from the contents watched by the reenactors, but he/she also poses others to analyze, for instance, the consequences of the battle in the short, medium and long terms, and the influence of the decisions taken by each character upon the ending of the event.

3.3. The debate stage

After the replay stage, also in the projection room, the expert drives a collective brainstorming about the consequences of the conflict in the short, medium and long terms. The goal is to provide the participants with a dynamic big board to display comments posted by the participants, which can be rearranged by the expert as the debate goes on. At any time, the expert can choose multimedia contents to illustrate the different points that are raised. Participants type their comments using the tactile mobile devices, and, if chosen by the expert, they have the possibility to explain their ideas or viewpoints to the whole audience as in an audio- or video-call. Some arguments can be voted upon, or socially rated as "possible" or "impossible", "likely" or "not likely", "interesting", "absurd" or "original", so that some of the most active participants get some kind of recognition. Likewise, this stage also considers quiz games to appraise the participants' understanding of the importance and impact of the battle.

Since the Battle of Thermopylae was not at all decisive, but rather has to be considered in the broader context of the Greco-Persian wars, the social discussion (supervised by the expert)

should deal with the consequences of these wars and what might have been different in History if things had happened differently. The topics we have considered in our experiments in this last stage of our technology-driven learning experience are the following ones:

- Would Xerxes have feared about being trapped in Europe if the Persians had not found such strong opposition in Thermopylae?
- Would there be fewer ruins in Athens today if Leonidas had stopped the Persians' advance? Would the Parthenon ever have been built?
- Would the Persians have conquered the whole of Europe? If so, would all European countries be like Turkey today? Actually, would there be countries?
- Would the Persians have conquered the North of Africa, too?
- Who would have been the Persians' greatest rivals: the Macedons led by Alexander the Great the next century, the Carthaginians a little bit later, the Celts, the Vikings, etc.?
- Would there have been Persian equivalents to Socrates, Plato and Aristotle?
- Would science have developed better or worse? There would have been no great Greek mathematicians, but maybe neither such a dark period as the Middle Ages?
- Would the industrial revolution have taken place? Would the impact of human on the natural environment be greater or smaller?
- Would the Europeans have discovered America, or would someone from America have crossed the Atlantic Ocean the other way before? If so, who?
- What would our languages sound like?
- What about sports and music?
- Would we ever have heard of Christianity or Islam, or would Zoroastrianism get to be the predominant religion in the world?
- Would Iran have been a superpower as the USA are today?

4. Implementation details

The REENACT proposal has been developed on top of the Future Media Internet technological facility provided by the EXPERIMEDIA FP7 research project.² As explained in Salama et al. (2012), the technologies that reside in the EXPERIMEDIA facility have been encapsulated into four components:

- The *Experiment Content Component* (ECC) monitors, derives experimental data from, and manages the other components, taking control of installation, deployment at the experimentation venues, running and termination. It elicits *Quality of Service* (QoS), *Quality of Experience* (QoE) and *Quality of Community* (QoC) data from the other components and delivers the measured values to the experimenters so they can analyze the behavior of technical systems in relation to user experience.
- The *Social Content Component* (SCC) gathers and manages data that is generated on social networking sites during the course of an experiment. Internally, it provides access to different social networks (giving read access and publishing capabilities) and also communicates social network monitoring metrics to the ECC.
- The *AudioVisual Content Component* (AVCC) provides a set of services related to the management and delivery of audiovisual contents, including acquisition from a media producer, adaptation and distribution to different platforms, live edition and realisation, and data and metadata synchronization.

- Finally, the *Pervasive Content Component* (PCC) provides means to track the users' locations as a means by which AR-based content can be selected for delivery and user-generated data can be mapped to a spatial location. The PCC hosts an augmented reality platform and an online environment for the orchestration of distributed live games.

As depicted in Fig. 1, the REENACT system comprises one server and interfaces for the reenactors, the expert and the experimenters themselves, which will (directly or indirectly) rely on/interact with the components of the EXPERIMEDIA facility and some of the resources available in the experimentation venues. The four components are:

- The *reenactors' front-end*: this is an Android application that delivers the interactions envisaged for the participants during the reenactment, replay and debate stages. It relies on the PCC to render the augmented reality vision of the reenactments on the participants' tactile mobile devices, and on the SCC to support messaging, ratings and so on during the replay and debate. It also interacts with the AVCC to control the flows of text, images and audio entering and leaving each tactile mobile device.
- The *expert's front-end*: this is a web application providing the functionalities needed by the expert to conduct the replay and debate stages. It interacts primarily with the AVCC, to allow the experts not to be physically present at the experimentation venues and to retrieve the multimedia contents to illustrate the situations arisen during the reenactments. The expert's participation will be realized through the SCC as for the other participants. Finally, the expert's front-end provides means to manage the arguments raised during the debate, including some features of real-time parsing (e.g., to highlight key words), searching, and filtering of text messages in cases of foul language or disrespectful/offending comments.
- The *experimenter's front-end*: this is an Android application that allows to supervise the operation of the rest of the elements during the REENACT experiences, including manual control over the orchestration of events, means to monitor the reenactors' activities (e.g., whether they stay within the reenactors' app or temporarily switch to other apps in the mobile devices) and elements to browse the information gathered about QoS, QoE and QoC metrics.
- The *REENACT server*: this is a centralized point for the other components to access pre-recorded contents and streaming flows through the AVCC of the EXPERIMEDIA facility, to store the records of events raised during the reenactments, to control what is displayed on the projection screen used during the replay and debate stages, and to upload data to the ECC for later evaluation.

Detailed descriptions of the components of the REENACT system are given in the following subsections.

4.1. The reenactor's front-end

The reenactors' front-end has been developed as an Android application that delivers the interactions envisaged for the participants during the reenactment, replay and debate stages. The Android application can be split in: (i) a *main activity* to inform the reenactors about their location and give additional indications and choices to go on in the reenactment, (ii) *other activities* intended to sustain the immersive and entertainment aspects of the REENACT experiences, (iii) a *coordination service* to control the flow between the previous activities, and (iv) the *social room* where the replay and debate stages take place. Details about each

² Information about this EU research project is available at <http://www.experimedia.eu>.

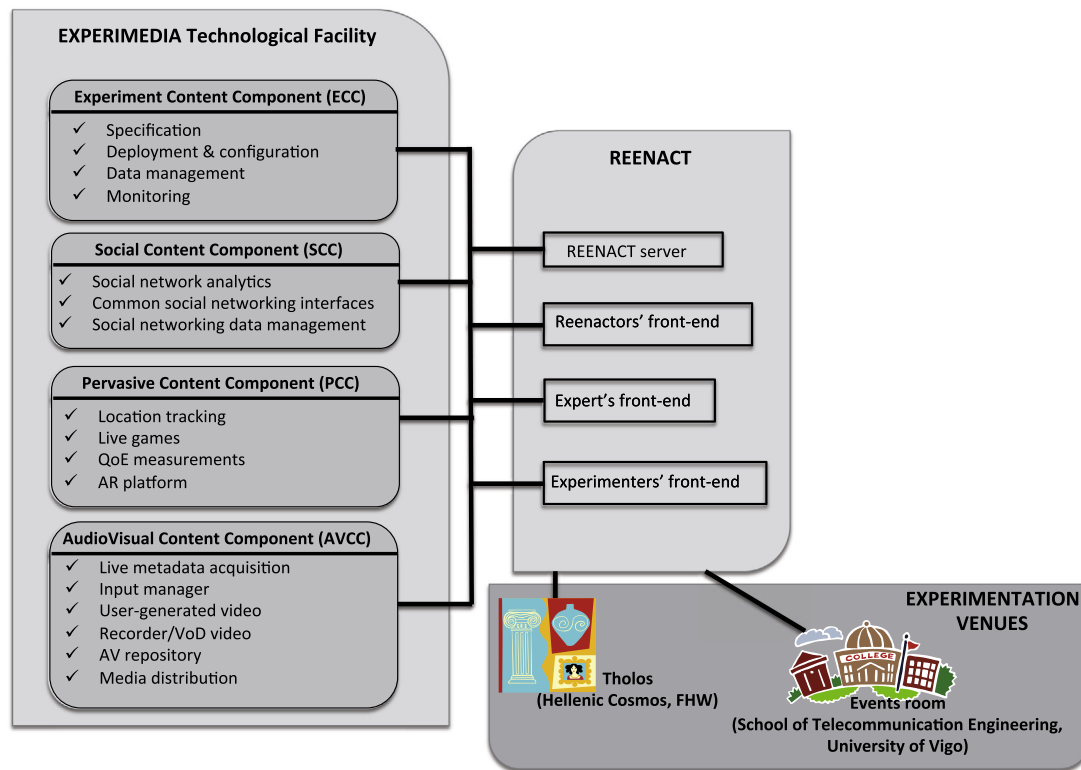


Fig. 1. Main functional blocks of REENACT and technological components of the EXPERIMEDIA facility.

one of these parts of the reenactors' front-end are described in the next sections.

4.1.1. The main activity

Following the election of a role in the reenactment and the indication of what other participants are known to the user, the main activity of the reenactors' application is the place where the user is informed of his/her own position during the reenactment stage, where he/she can browse multimedia contents describing the current state of things, and where he/she is given indications and choices to go on in the reenactment. To this aim, the screen of the mobile device is split as shown in the snapshots of Fig. 2.

On the top half of the screen, one or several pieces of multimedia content are arranged in a horizontally-scrollable panel, right after the menu of indications and choices to go on (these will be always displayed as the first item on the panel). The data are retrieved from the AVCC or the REENACT server. On the bottom half, an interactive map (built on top of Google Maps API for Android) is displaying the relevant locations of the Battle of Thermopylae, including a representation of the reenactors' positions. The map can display 3 different scenes:

- The first scene (appearing on the left of Fig. 2) situates the main locations during the prelude of the battle: Asia Minor, the Hellespont, Thessaly, Phocis, Thebes, Corinth, Arcadia and Sparta.
- The second scene (appearing on the right of Fig. 2) displays the relevant locations during the course of the fights in the Thermopylae area: the Persian camp, the Greek camp, the old Phocian wall, the Anopaeon path and the Greek rearguard. These locations can appear either on a satellite view of the area (as seen nowadays) or with an ancient historical map overlaid on it, which helps the user understand how the area has changed over the centuries due to a process of sedimentary deposition that has moved the coastline far apart from the mountains.

- Finally, the third scene displays three afterlife locations to host participants whose characters die during the reenactment: the Elysium (Greek heaven), the Tartarus (Greek underworld) and the Garothman (Zoroastrianism heaven).

One final element on the screen is one User Interface (UI) component intended to gather data from the reenactors for one of the QoE metrics. It is basically a progress bar that the user can drag from a neutral position to the negative side or the positive side, changing the thumb accordingly to display emoticons from very sad/bored to very happy/excited. The thumb gradually moves back to neutral position as a means to ask the user to refresh. The implementation of this component reports data to a tool provided by the PCC of the EXPERIMEDIA facility.

4.1.2. Other activities for the reenactment stage

During the reenactment stage, the users are faced from time to time with other activities intended to sustain the immersive and entertainment aspects of the REENACT experiences.

- The first activity for immersion is intended to deliver 3D views of certain locations, putting the user inside a cubemap that he/she can move around by rotating the mobile device. This way, he/she can see him/herself inside the scenery of certain locations. The implementation of this activity relies on *min3d*,³ a 3D library/framework for Android using Java and OpenGL ES. The code is general in the sense that it can be made to display several views by indicating different parameters on startup. As an example, in Fig. 3 we depicted the sides of the cubemap used to render the Persian camp at Thermopylae showed in Fig. 4 (which has been developed thanks to images provided by the Virtual Reality department of the FHW).

³ <https://code.google.com/p/min3d/>.

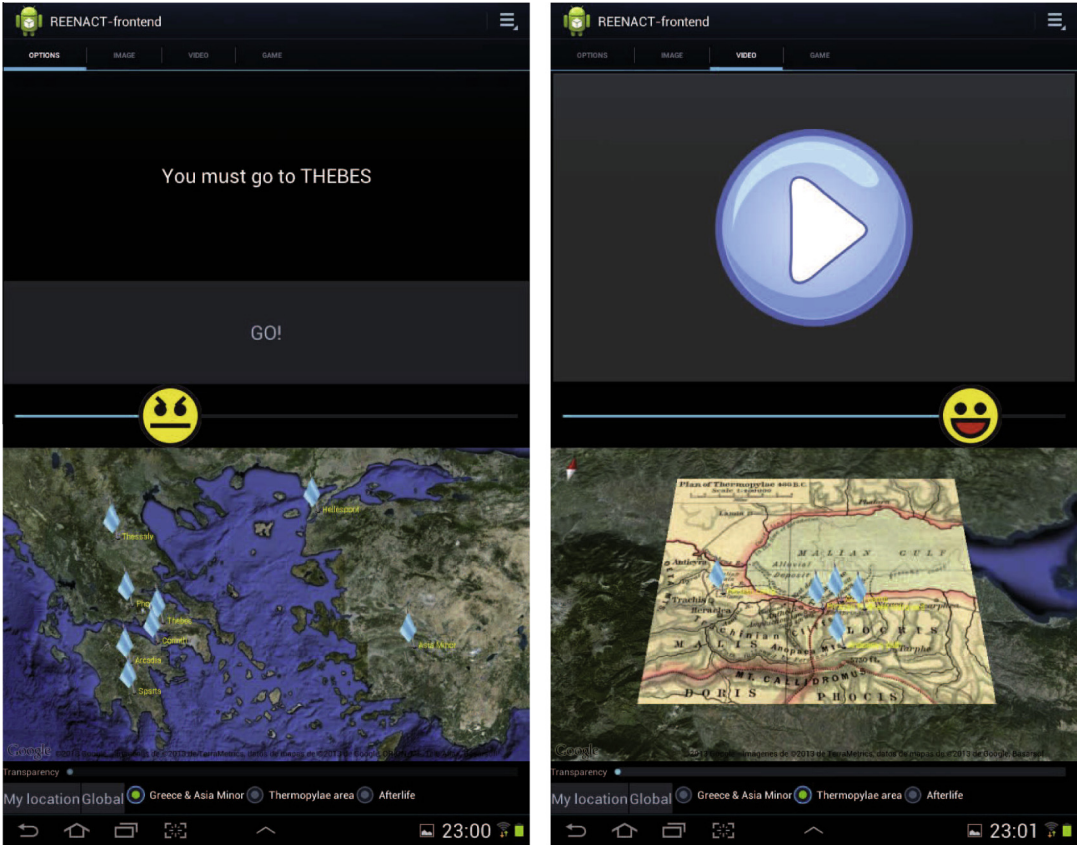


Fig. 2. Snapshots of the main activity of the reenactors' front-end.

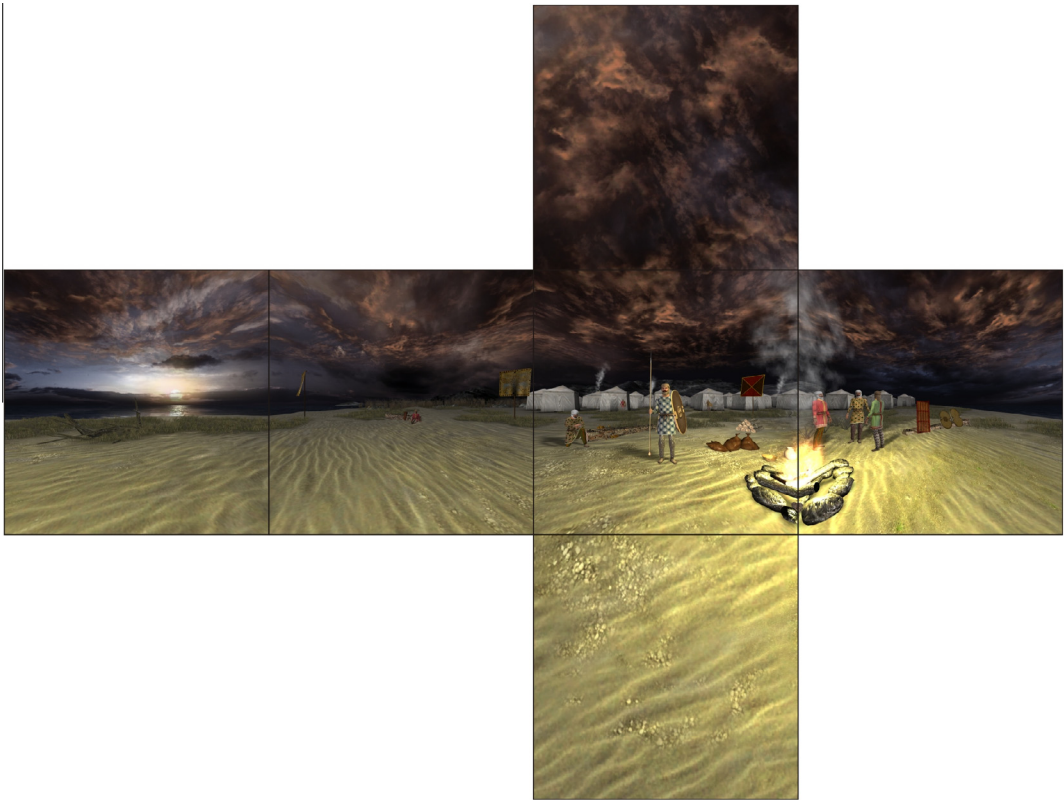


Fig. 3. Sides of the cubemap used to render the Persian camp at Thermopylae.



Fig. 4. Snapshots of the 3D views of the Persian camp at Thermopylae.

- The second key activity is the so-called *ZonesNavigator*, which is an AR application built on top of the Metaio AR framework⁴ that has been widely adopted in multiple application domains for visualization of 3D models and diverse furniture into an image, which can be even integrated in real time in the environment of each user (Kurz & BenHimane, 2012; Kurz, Meier, Plopski, & Klinker, 2013; Kurz, Meier, Plopski, & Klinker, 2014; Kurz, Olszowski, & BenHimane, 2012). The activity manages a number of 2D codes, one corresponding to each location, and tells the user to move around to find a particular one. Once he/she is there, a “Check-in” button is enabled to confirm that the user has made the movement requested by the reenactment script. The 2D codes are linked to 3D models (again, provided by the FHW) representative of each one of the locations. An example is shown in the snapshot of Fig. 5.

The entertainment aspects of the reenactment stage are furnished by game activities to simulate sword fighting, arrow launching and the building of a pass across the Hellespont. These games are quite simple because the users will only spend up to 1 or 2 min with them. Besides, simple logical puzzles (adapted from Simon Tatham’s collection⁵) are also offered to fill dead times waiting for other reenactors’ decisions or actions.

- The game of Fig. 6 becomes available to Persian and Greek soldiers when they have just arrived in their respective camps at Thermopylae. They are told that the goal is to place a certain number of tents in empty squares next to trees, in such a way that no two tents are adjacent (even diagonally) for the sake of intimacy, and that the number of tents in each row and column matches the numbers around the edge of the grid.
- The game of Fig. 7 becomes available to the reenactor playing the role of King Xerxes whenever his soldiers are fighting at Thermopylae. The goal is to paint the map with four colors so that no two adjacent regions have the same color, as pretending that the King is wondering about the administration of the new conquered lands.

The last relevant activity for the reenactment stage is called *FullScreenContentActivity*, which is in charge of full-screen displaying images and videos of high quality without increasing

excessively the memory demands of the main activity and without complicating the design of the front-end’s interface.

4.1.3. The coordinator service

The flow between the activities of the reenactors’ front-end enumerated in the preceding section (the main activity, the 360° views, the *ZonesNavigator* and the *FullScreenContentActivity*) is controlled by an Android service running continually in the background. This service communicates with the activities by using a simple messaging protocol built on top of Java classes. It also centralizes the communications between each tablet and the REENACT server, exchanging XML-formatted messages like the ones shown in Tables 1 and 2 through a RESTful interface (where the reenactor with the tablet 1 and whose nickname is “noresnau” asks the server for a role, being the Persian King Xerxes finally assigned to him).

4.1.4. The social room

Following the reenactment stage, the reenactors’ front-end switches to the social room, the virtual space where the replay and debate stages take place. We have developed the following social functionalities starting from the utilities included in the SCC of the EXPERIMEDIA facility:

- One activity to access the chatting room.
- One activity to deal with multiple-choice questions.
- One activity to browse the ratings given by the different users to the comments, questions and answers provided by each individual. This activity is not thought to provide the reenactors with information, but rather it is just gathering part of the data that will be uploaded to the ECC regarding QoC metrics.

The social room has mechanisms to filter foul language and to highlight key words, which are implemented locally in the Android application. Offensive language is filtered by resorting to a dictionary of swear words that is locally stored in the Android application, which prevents the reenactors from entering rude terms. The highlighting of key words allows the experts to attract the reenactors’ attention on relevant issues in the discussion topics handled in the replay and debate stages. To this aim, the expressions to be highlighted must be lodged between <h> and </h> tags. Once the messages have been formatted, they are published as posts on the wall of a particular Facebook event (which must be previously set up), and finally processed by the Android application to be shown to the reenactors. Note that we started from a

⁴ www.metaio.com.

⁵ www.chiark.greenend.org.uk/sgtatham/puzzles/.



Fig. 5. A snapshot of the Zones Navigator, instructing the user to go to the destination of Thebes while he/she is closer to the Greek camp at Thermopylae.

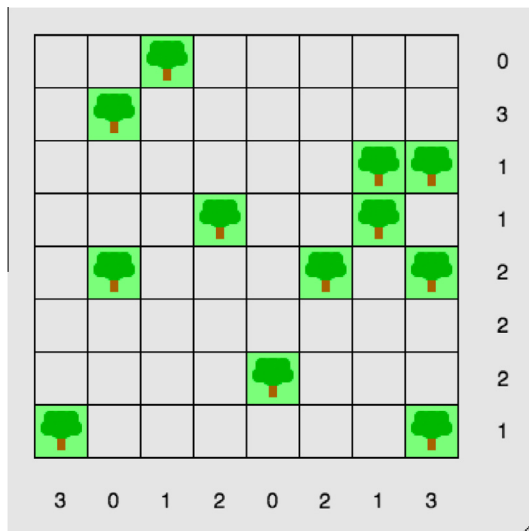


Fig. 6. A snapshot of the game about placing tents in areas next to trees.

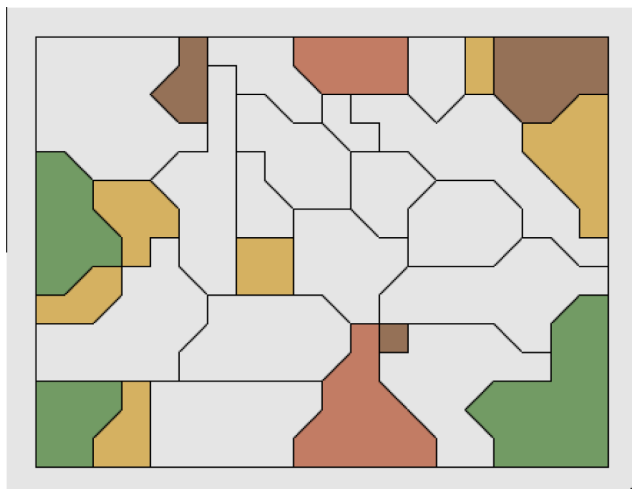


Fig. 7. A snapshot of the game about painting a map with different colors.

Facebook event to control the flow of posts published by the participants and experts because this design decision was previously taken in the implementation of the Social Content Component included in the EXPERIMEDIA facility.

During the replay stage, the experts can pose multiple-choice questions to the reenactors by publishing posts on the Facebook event wall as per XML-formatting guidelines. These messages are automatically processed by the Android application, which organizes each question and the possible answers in an expandable list, as shown in Fig. 8.

The social room also presents rankings with the users who have got the highest number of right questions, along with tabs where the responses and comments given by other users can be viewed and rated, as shown in Fig. 9. As we will describe in our experimental validation, this feedback is especially useful when it comes to assessing the impact of our pedagogical approach in terms of indicators derived from QoC metrics.

4.2. The expert's front-end

The expert's front-end is a web application (accessible through a web browser) providing the functionalities needed by the expert to conduct the replay and debate stages of the REENACT experiences. The (web-based) frontend supports the following features, as shown in the snapshot of Fig. 10:

- Accessing the social room to interact with the other participants by means of textual comments and to deliver multiple-choice questions, using the same XML-compliant markup as the reenactors' front-end for formatting.
- Browsing the activities of the reenactors during the reenactment stage, displaying a timeline with the sequence of states they have been through (bottom half of Fig. 10). The states relate directly to the contents offered to the participants at the different moments, which is the main aid for the expert to organize the points he/she will be making. Clicking on the box that represents one state, the front-end displays a list of the contents offered to the reenactors while they were in that state. Clicking on an item of the list opens a pop-up window where the expert can see the material him/herself. The sequence of contents displayed on the big screens of the reenactment space is displayed, too. The contents available in the repository help the expert to support his/her explanations about the battle

Table 1

Message used by the reenactor's tablet to ask the REENACT for a role.

```
<?xml version="1.0" encoding="iso-8859-1"?>
<REENACT_MESSAGE xmlns="http://www.experimedia.det.uvigo.es"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.experimedia.det.uvigo.es/Reenact_protocol.xsd">
<REENACT_REQUEST>
<REQUEST_ID>1234</REQUEST_ID>
<METHOD OP_NAME="getRole">2</METHOD>
<PARAMETERS>
<TableT_ID>1</TableT_ID>
<USER_ID>noresnau</USER_ID>
</PARAMETERS>
</REENACT_REQUEST>
</REENACT_MESSAGE>
```

Table 2

Message used by REENACT server to communicate the chosen role to the reenactor's tablet.

```
<?xml version="1.0" encoding="iso-8859-1"?>
<REENACT_MESSAGE xmlns="http://www.experimedia.det.uvigo.es"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.experimedia.det.uvigo.es/Reenact_protocol.xsd">
<REENACT_RESPONSE>
<REQUEST_ID>1234</REQUEST_ID>
<METHOD OP_NAME="getRole">2</METHOD>
<RESPONSE_STATUS STATUS_NAME="OK">0</RESPONSE_STATUS>
<RESPONSE_DATA>
<TableT_ID>1</TableT_ID>
<USER_ID>noresnau</USER_ID>
<ROLE_INFO>
<ROLE_ID>2</ROLE_ID>
<ROLE_NAME>King Xerxes</ROLE_NAME>
</ROLE_INFO>
</RESPONSE_DATA>
</REENACT_RESPONSE>
</REENACT_MESSAGE>
```

during the replay and debate stages. Actually, the expert's front-end includes a smart agent that automatically selects and shows a list of the most appropriate contents for each state (ordered as per their relevance), by matching their respective tags (which have been manually entered in the database of the system in order to support the expert's queries). Besides, the frontend allows the expert to retrieve external references from the Internet.

- Delivering the output of the expert's webcam to a remote location. The component implementing this feature (shown in the middle of the top half of Fig. 10) relies on W3C's WebRTC API, that works best within Google Chrome.
- Streaming of the audio and video from the projection room of the replay and debate stages to the expert's computer (upper right corner of the expert's screen).

4.3. The experimenter's front-end

The experimenter's front-end provides the interfaces needed to supervise the operation of the rest of the elements in REENACT. As we mentioned in Section 4, it is an Android application with very simple interfaces for the following features:

- Displaying information about the state of each reenactor in the game during the reenactment stage.
- Indicating which events are expected from each participant at any time, as a means to check whether someone is stuck or lost for some reason.
- Recording whether the participants remain during the reenactors' front-end during the reenactment or they do switch to use other applications on the tablet (this will be data to be uploaded to the ECC as an indicator of QoE).

- Allowing the experimenters to participate in the social room during the replay and debate stages, which makes sense especially when the REENACT sessions are supervised by museum guides or educators.

Since the experimenters do not need to move around, they can use a bigger device than the reenactors. That is the reason why the interfaces of the experimenter's front-end were designed considering the target of a 10-inch tablet (versus tablets between 5 and 8 inches that were used by the reenactors, as we will describe in our experimental validation).

4.4. The REENACT server

The REENACT server has been deployed to centralize access to the audiovisual contents served by the AVCC of the EXPERIMEDIA facility, including the following features:

- Ability to stream around 15/20 preencoded videos to a number of Android devices with up to 1280 × 800 resolution and considering a maximum bit rate of 3 Mbit/s.
- Ability to streaming the audio and video feeds coming out of the expert's webcam to the projection room in each experimentation venue (high quality).
- Streaming from the projection room to the expert's front-end.

This AVCC configuration has been tuned to store pieces of text and images that may be used by the reenactors' front-end or the expert's front-end for illustration purposes at any time, in addition to the audiovisual contents. The REENACT server is also the place to store the records of events raised during the reenactments. To this aim, a database has been implemented that can be queried (by any

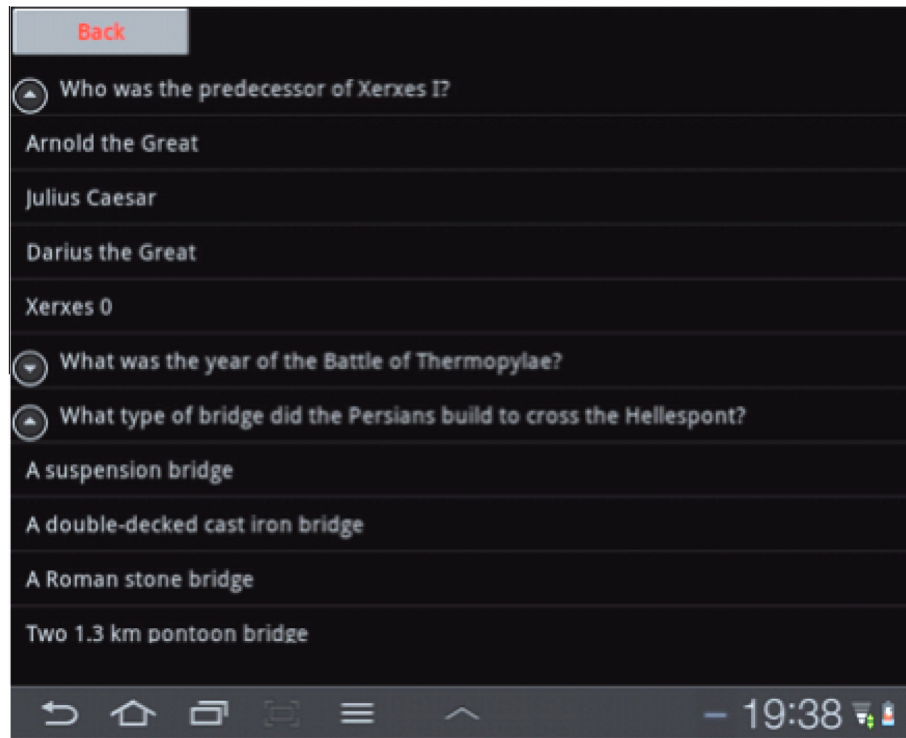


Fig. 8. Expandable list showing the multiple-choice questions posed by an expert to reenactors.

of the front-ends) through a RESTful interface. It is also possible for clients to subscribe to the notification of events, as needed for the reenactors' app to display up-to-date information about all the participants.

5. Experimental validation and results

5.1. Goals

Our experiments were intended to measure and assess the value of the REENACT pedagogical proposal in terms of key performance indicators derived from *Quality of Service* (QoS), *Quality of Experience* (QoE), and *Quality of Community* (QoC) metrics. As just its name suggests, the Experiment Control Component (ECC) of the EXPERIMEDIA facility was set up to monitor a number of parameters related to each type of metric, whereas the rest of data were extracted from a questionnaire delivered to the users at the end of the experimentation session. Next, we detail the meaning of each metric along with the parameters that we have considered in its measurement.

5.1.1. About QoS

QoS data reflects direct, objective measurements of physical characteristics of the environment of an experiment or the performance characteristics of software or hardware components. Some of the parameters we have considered regarding this metric in our tests have to do with (i) the responsiveness of the interfaces offered during the reenactment stage, which clearly depends on the memory and computing power of the mobile devices, especially in what concerns the augmented reality features and the reproduction of locally-stored or streamed videos, (ii) the battery consumption of the participants' tactile mobile devices, (iii) the bandwidth requirements to support the three stages of our approach, (iv) the responsiveness of the communication with the different pieces of software lodged remotely in the EXPERIMEDIA

facility, and (v) the promptness of the interfaces provided to the expert to locate relevant material to illustrate situations arisen during the replays and arguments raised during the debates.

5.1.2. About QoE

The main input to assess the Quality of Experience was the questionnaire delivered to the participants at the end of the experiment, where they could provide textual comments and rate diverse aspects of the REENACT pedagogical experience, including the educational potential of the approach, the level of entertainment, the quality and completeness of the contents available about the Battle of Thermopylae, the interest of the approach for museums and educational institutions, along with the value of the reenactment game, interactive maps, video footage, or multiple-choice questions, among other features.

The voting and quiz games offered during the replay and debate stages were also used as sources of information about the participants' level of engagement and learning about the historical events.

Besides, as a research question, we also checked whether any of the aforementioned parameters depends on the roles played by the participants during the reenactment stage, since it might happen that the QoE measurements are better for someone who has played a main role (say, King Xerxes in the Battle of Thermopylae) than for someone who has played a secondary role (e.g., a Persian infantryman), or maybe that differences appear between winning and losing sides.

5.1.3. About QoC

QoC measurements, again, reflect both quantitative and qualitative aspects of the community of people that participate in a REENACT session. To this aim, the experimenters primarily looked at the interactions among the participants during the replay and debate stages, e.g., counting the number of ratings and analyzing the length, mood and depth of the comments they exchange using their tactile mobile devices. Actually, the comments exchanged

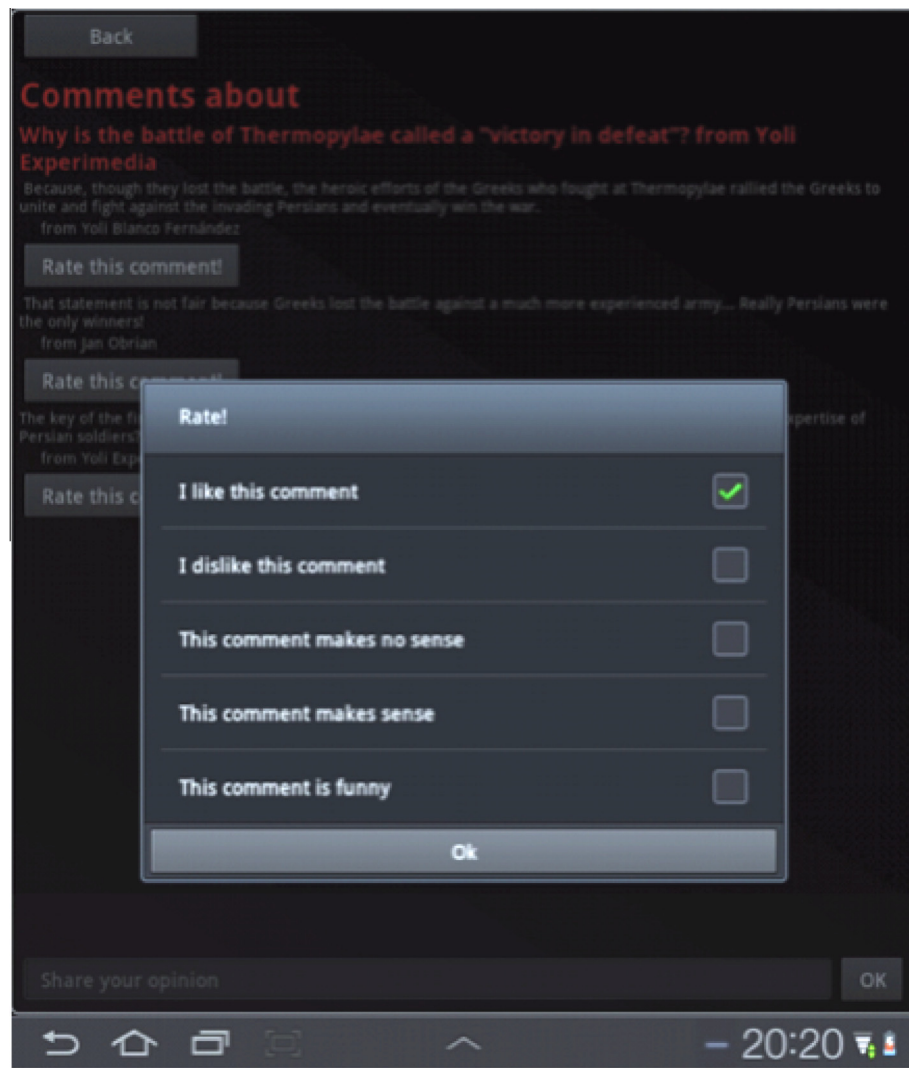


Fig. 9. Rating reenactors' comments under a discussion topic posed by an expert.

by the reenactors have been analyzed in our approach by a manual process supported by basic NLP metrics, which allow, for example, to count the number of words or to look for occurrences of terms from dictionaries of foul language and different moods.

Special attention was paid to what happens among people who did not know each other before, for which they will all be asked to tick out the nicknames of their acquaintances right before starting the reenactment stage. Thus, it would be possible to address questions like whether strangers keep distances during the reenactment, whether they comment on the others' arguments, whether there is any apparent bias in the ratings given to acquaintances and strangers, etc.

Some subjective input from the experimenters were also sought over the different experimentation sessions, to rate the general mood of the participants during the reenactment stage: were they engaged? were they apparently bored or having fun? did they dare to talk aloud when required by their roles?.

5.2. Description of our experiments

The core of the experimentation for REENACT was conducted during the summer of 2013 in the Hellenic Cosmos, the venue provided by the FHW in Athens. Specifically, the reply and debate stages were carried out in the Tholos, as shown in Fig. 11 where

the expert interacts remotely with the participants by the frontend depicted in Fig. 10.

The FHW itself and the University of Peloponnese recruited participants among their communities of visitors, students, researchers and other staff. The FHW testing plan was supplemented by the University of Vigo (the institution which the authors of the paper belong to) with *ex ante* experimentation sessions in the School of Telecommunication Engineering between May 27th and June 7th (to get early feedback and fix defects in the software or in the experiment design) and *ex post* sessions between July 22nd and August 9th (to gather further evidence for the evaluation). Again, participants were recruited among the communities of students, researchers and other staff of the University of Vigo. Regarding the number of users involved in the experiments and the amount of experimentation sessions completed in each location, note that 19 users participated in the experiences in the Hellenic Cosmos during 4 sessions, whereas 42 users joined to the experiments in the University of Vigo during 7 sessions. In both cases, we formed groups of 6 participants and dealt with the 6 mandatory roles described in the Appendix A.

We asked all users to sign an informed consent where they granted us with the right to maintain and process the information generated through a mobile device during the course of the experiment, plus their replies to the questionnaire delivered at the end

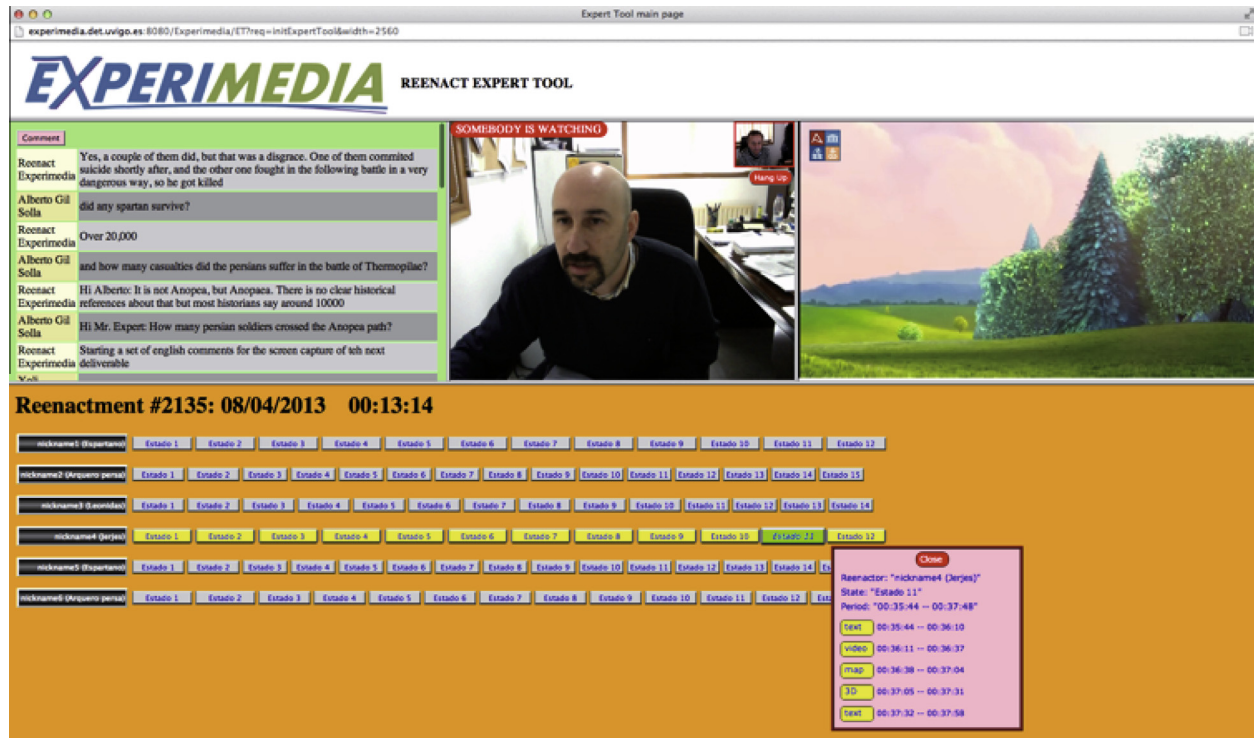


Fig. 10. A snapshot of the expert's front-end.

of testing. These data are only available to the experimenters for testing purposes, not having any commercial intention behind. For the sake of privacy, no personal data were handled, monitored or recorded, so that the personal details of each user (name and surname) only existed in the signed informed consent.

Regarding the mobile devices, the tests in the Hellenic Cosmos in Greece involved Samsung Table 7.7-inch tablets (which were lent by the experimenters), whereas in the experimentation sessions in Vigo we allow the users to participate with smartphones

and tablets of their own. The features required for the testing devices are overviewed next:

- Screens between 5 and 8 inches: smaller ones would not fit the amount of information to display, whereas bigger one would not be comfortable to move around during the experimentation session.
- Rear camera, gyroscope, compass and other sensors to support immersive experiences.



Fig. 11. The expert intervening remotely in the replay stage of a REENACT session.

- Sufficient computing power to run the augmented reality features and to manage 3D contents and high-definition multimedia.
- A recent version of the Android operating system.

In order to ensure a rapid familiarity with the available software, the interfaces of the expert's front-end and the participants' applications have been designed with an eye towards simplicity, so that they were intuitive enough and easy to use. The expert was provided with a brief reference manual containing key instructions to drive the replay and debate stages. Regarding the participants, the experimenters gave them some basic guidelines before the tests (for about 5 min), telling them how to proceed during the reenactment and how to interact with the expert afterwards.

5.3. Experimental results

Having presented the parameters measured in each type of metric considered in our tests, we are ready to describe the experimental results achieved after the sessions in Athens and Vigo and discuss the main findings.

5.3.1. Quality of Service (QoS)

Regarding the QoS, in terms of CPU and memory usage, it was found that none of the features of the reenactors' app exceeded the capabilities of the device, even though the augmented reality navigation (due to the identification and processing of the 2D markers plus the rendering of the 3D models) reached peaks of 80% CPU and 55% memory usage. This fact suggests that devices with lower specifications could have problems while running the app – at least, the users would have to face longer loading times. Yet, the biggest concern in this regard relates to the splash screens displayed while loading the Metaio software, which caused severe delays (up to 20 s) not related to any computations, but rather to the fact that REENACT was using a free version of Metaio.

In regard to battery consumption, it was found that the whole REENACT experiences – with up to 20 min for replay and debate – would take up an average of 43% of the full capacity (5100 mAh). The greatest contributions were due to the AR processing and the Wi-Fi communications through the REENACT server. Screen activity also has an effect, to the point that a simple implementation feature like preventing it from turning off (following periods of inactivity) could add up to 15% consumption from the end of the reenactment stage to the end of the debate.

With respect to bandwidth requirements, we did not find problems with the real-time interaction among users and the transmission of multimedia information using a Wi-Fi network with 10 Mbps. This is mainly due to the fact that the script of the reenactment makes it possible to schedule the delivery of multimedia contents to the participants' devices according to their current state and the possible transitions from it. This way, the devices can prefetch contents from the AVCC or the REENACT server so that they can be displayed timely. Likewise, we can ensure constant use of bandwidth during the reenactment stage, which is the most demanding in terms of BW. The demands are much lower during the replay and debate stages, inasmuch as there is only one flow of multimedia data from the expert to the participants' devices.

Regarding the responsiveness of the communication with the EXPERIMEDIA facility, note that the videos delivered to the reenactors' app from the REENACT server could be displayed in native resolution (1280 × 800 pixels) with an average latency of 3.2 s, which nobody complained about. Finally, the transmission of the expert's video feed was relayed in a configuration using the AVCC component of the EXPERIMEDIA facility that worked flawlessly in all the scenarios. Besides, there were no problems regarding connectivity or latencies at any time, and the expert's participation in the replay and debate could be handled practically in real time.

5.3.2. Quality of Experience (QOE)

Analyzing the results obtained in relation to the QoE requires to have a look the responses that the 61 users involved in our tests (19 in Athens and 42 in Vigo) provided us via the questionnaires delivered at the end of the testing sessions, which are depicted in Table 3. The averaged ratings ranges from 1 (least positive, strong disagree, a little bit...) to 5 (most positive, strong agree, quite a lot...).

Overall, the ratings were quite positive: the average rating for point (1) in Table 3 suggests that it is not really necessary to create a wealth of content about an event, since it appears to be more important to ensure that all the participants have something to do at every time during the reenactment stage – dead times allowed by the current script of the Battle of Thermopylae had a negative impact on point (3). The same goes for the dead times while waiting for the AR framework to load, which several participants criticized as severe drawbacks (especially for children and teenagers, who tend to be more impatient than adults).

Points (2), (4), and (5) show that participants, in general, appreciate the novelty and potential value of the REENACT

Table 3

Average ratings given by the participants in our experiments about QoE-related parameters.

(1)	Quality and completeness of contents used for the Battle of Thermopylae	3.5
(2)	Educational potential of the REENACT approach...	
	...for children	4.1
	...for teenagers	3.9
	...for adults	4.3
(3)	Level of entertainment...	
	...for children	3.4
	...for teenagers	3.1
	...for adults	4
(4)	Opinion about REENACT as a valuable asset for History-related museums	4.4
(5)	Opinion about REENACT as a valuable asset for educational institutions	4.1
(6)	Value and interest of the reenactment game	4.4
(7)	Value and interest of the interactive maps	4.1
(8)	Value and interest of 360° views	4.6
(9)	Value and interest of the augmented-reality features	3.4
(10)	Value and interest of video footage	3.8
(11)	Value and interest of background music	3.2
(12)	Value and interest of the expert's audio and video feeds	3.7
(13)	Value and interest of multiple-choice questions	3.8
(14)	Value and interest of social networking among participants in REENACT.	3.1

proposal when concerning History-related museums and educational institutions. These are positive findings that can make us think about further development and actual commercial exploitation of the REENACT system. Points (6) to (14) are ratings for different technical features of the REENACT system. The lowest values highlight points that should be improved in the future. Criticism regarding the AR features was, most likely, not due to a lack of appeal on the participant side, but rather to the long loading times that caused a sensation of tiredness every time the script required one person to move from one place of the reenactment space to another. The background music was expressed as being “difficult to notice” most of the times. Finally, the social networking features were criticized for being “little more than one chat” in the current state of implementation, and many participants expected to find something closer to what they can do on Facebook.

The aforementioned comments relating to the mood of the participants during the REENACT experiences were in line with the numbers reported by the mood control available on the main screen of the reenactors’ app (recall Fig. 2). Analysis of the data gathered by the ECC, coupled with the events recorded during the reenactment stage, showed that participants had positive mood most of the time. Bad mood was only apparent sometimes after returning from the AR navigator and during idle times allowed by the current script of the Battle of Thermopylae.

The following are some of the comments gathered in the free text boxes included at the end of the questionnaire.

- “It would be nice if you could return to the augmented reality features once you have found where you needed to go.”
- “The 360° views should be enriched to enable more interactions than just looking around.”
- “More decision paths (potential ends) should be added to the gameplay.”
- “The usability of the application would further improve with a consistent set of symbols to be used.”
- “I would like to have more videos and mini-games.”
- “The game of reenactment should be faster and not have so much waiting. The AR should also be available during the waiting.”
- “Smart idea. You have to try more about speed!”
- “I see great values for museum here, to teach about events in the regional scope.”
- “You get significantly different experiences depending on the role you are given. As Ephialtes, I was idle for very long times.”

The experts’ opinions were also assessed in conversations with the experimenters. In general, they appreciated the information provided by the experts’ front-end, but they agreed it would have been useful to have other sources of feedback from the reenactors apart from the chat. Yet, they did not think that a live video feed from the conference room would help, especially under the dark environment inside the Tholos (in case of the FHW experimentation in Greece).

5.3.3. Quality of Community (QoC)

QoC measurements were aimed at checking whether the social activities sought during the reenactment stage and the replay and debate occurred uniformly or in “islands”, i.e., only among people who knew each other beforehand. To this aim, the reenactors’ app displayed a list of the nicknames of all the participants, so that each user would tick those of his/her acquaintances. With this data, the ECC recorded the following parameters:

- Number of ratings and comments entered in the social room.
- Number of ratings and comments between acquaintances.
- Ratio of positive/negative ratings between acquaintances.

Table 4

Some figures related to the QoC metrics.

Number of ratings and comments entered in the social room	273
Number of ratings and comments between acquaintances	151
Ratio of positive/negative ratings between acquaintances	61%
Number of ratings and comments between strangers	122
Ratio of positive/negative ratings between strangers	74%

- Number of ratings and comments between participants who did not know each other before the experiment.
- Ratio of positive/negative ratings between participants who did not know each other before the experiment.

Whereas subjective evaluations from the experimenters suggest that strangers did keep distances during the reenactment, analysis of the data gathered by the ECC for the aforementioned parameters revealed that there were nearly 24% more interactions between acquaintances than between strangers, but the ratio of positive/negative ratings was 13% better in the latter case, as if strangers would only blur distances for good. In Table 4, we presented the figures obtained in the measurement of QoC parameters.

Table 4 suggests that the participants in the REENACT experiences could actually be seen as a sporadic social network of people doing something together for some time, rather than just a group of people doing something in the same room. Actually, several users wrote comments asking for more sophisticated social networking features (e.g., linking to real Facebook accounts), but these went beyond the privacy limits imposed by the EXPERIMEDIA experimentation guidelines.

6. Conclusions and further work

In this paper we have described a novel pedagogical approach called REENACT which is intended to improve the understanding of historical events that are traditionally taught as a vague set of dates, good and evil forces, losers and winners. To attack this partial and deficient awareness, REENACT proposes to exploit tactile handheld devices, repositories of multimedia contents, an advanced technological facility and remote experts to make groups of people learn more about a certain battle or war both from the inside, as reenactors, and from the outside, as historians. Regarding the efficiency of the pedagogical approach, it was not our goal to measure how much each participant has learnt about the Battle of Thermopylae via REENACT. Actually, REENACT has been conceived as an activity for informal learning where the focus is put on the quality of edutainment experience and the participants’ satisfaction. Attempts to appraise the participants’ knowledge gains would have to rely on bookish questionnaires, which would conflict with the informal approach and with the fact that the participants of one REENACT session may have very different backgrounds and previous knowledge about the event in question. Anyway, considering the relevance feedback (questionnaires) provided after our tests in the Foundation of Hellenic World in Athens and the School of Telecommunication Engineering from the University of Vigo in Spain, the results are certainly good because participants recognized to have learnt new aspects about the Battle of Thermopylae thanks to the reenactment and the brainstorming driven by the expert.

Besides, the analysis of the data gathered during the course of both experimentation sessions revealed significant benefits for the different people involved in the pedagogical experiences:

- First, museum educators can participate in a new type of collective experience, supplementing the expertise and knowledge provided by the experts in replays and debates. REENACT brings

in possibilities to make the most of (possibly unused) spaces, technological facilities, content and personnel in venues like the FHW, offering of a new kind of collective experience to reinforce the understanding of events that have shaped the History of a certain area of the world.

- Museum visitors can enjoy new edutainment experiences aimed at improving the understanding of historic events, relying on social networking functionalities and augmented reality capabilities. They also have the opportunity of interacting with one another, and also with geographically distributed experts via user-friendly interfaces. The opinions gathered from the participants in the experiments reinforced the idea that REENACT is appealing to a wide audience. However, it seems necessary to redesign or reimplement some aspects to avoid idle times and waiting times that may have a negative effect on children and teenagers.
- Experts can offer their services to collaborate with museum educators in new pedagogical experiences, interacting more closely than ever before with people interested in knowing more about major historical events. They can efficiently browse repositories of multimedia contents to relate historical facts to specific situations lived by museum visitors during the reenactment of the events, providing annotations, images, diagrams, animations, video clips, etc. Besides, they can conduct live debates about the consequences of the fights in the short, medium and long terms. The feedback gathered from the historians involved in our tests confirmed their interest in participating in REENACT sessions as an additional outlet for their professional activities. They were curious about the proposal and emphasized the importance of having professional assessment in the debates, to prevent an a-historical reasoning process that may have exactly the opposite effects of those desired. Nonsensical questions could only speculate more and more hypotheses and not help to understand the complexity, interdependence and causality of the historical process.
- Content creators/providers can find an additional outlet for the multimedia contents they produce, which can be usable to provide historically-meaningful explanations to the situations arisen during the reenactments and to the arguments raised during the debates. Even though it was found that participants in the reenactment of the Battle of Thermopylae could be reasonably pleased with only a few pieces of content, they usually made comments asking for more stuff, especially videos and 3D views of the different locations of the game. Additional contents could be important to fill in idle times, too.

After our experimentation sessions, the above conclusions were confirmed again among the audience of two Spanish cultural events where the REENACT pedagogical approach has been presented recently. Specifically, the events *History in the media (Realidade aumentada e Historia, 2013)* (held in Ourense on April 2013) and *Relationships between creativity and culture (O sistema REENACT, 2013)* (in Santiago de Compostela, on September 2013) were aimed at (i) discussing the connection of History with other disciplines, making visible the role of the historians in the world and (ii) highlighting the relevance of technological tools in the construction of new cultural formats and services. In the realm of these events, it was also found that the REENACT proposal might be just as suitable for primary or secondary education institutions as well as for History-related museums. Educators encountered at divulgation events and research conferences (as well as some who participated in the experiments themselves) highlighted the potential interest of the idea and asked us to keep developing the system together with new scenarios. Actually, thanks to its flexible and modular architecture, the REENACT system can deal with new historical events without major modifications. Actually, the interfaces of the social room

(provided to the participants for the replay and debate phases) and those shown from the expert's frontend do not need to be changed at all. Also, the technological platform of the approach is directly reused for new historical events. The effort of developing new scenarios has to do with the following tasks:

1. Creation of new AR markers and contents to illustrate the course of the event. Contents could be reused from the material owned by a cultural institution (just like we did with the FHW for the Battle of Thermopylae) or retrieved/linked from external sources via the Internet.
2. Implementation of the new reenactment script in the formalisms handled by our reenactment engine. The logic that supports the state machine could be reused without modifications.
3. Tagging the new audiovisual contents and the states allowed by the reenactment script, so that the former can be queried by the expert and presented to the participants.

Regarding possible extensions to REENACT, our further work is narrowly-related to the limitations identified by the participants in the experimentation sessions. Mainly, we plan to (i) improve the social interface of the reenactors' front-end by incorporating most of the typical functionalities available in current on-line communities, (ii) optimise the provision of AR features in order to lessen the long loading times identified by the participants of our tests, and (iii) analyze new possibilities regarding the content creation to avoid the negative effects derived from idle and waiting times suffered by certain roles during the reenactment. Besides, with the goal of exploiting the technology developed in REENACT, we plan to design a platform intended to automatically establish sporadic social networks among people (acquaintances or strangers) who happen to be physically close to one another at a certain moment. The goal will be to provide solutions to (i) establish ad hoc connections among nearby mobile devices and (ii) automatically identify the most relevant pieces of information to deliver at any time. The platform will be applicable in various areas, ranging from the formation of groups and the orchestration of activities around events or venues that attract people with potentially related interests (e.g., museums, concert halls or campsites) to opportunities for enhanced communications and access to relevant information on the road (advanced information services to vehicular networks) or advances in the vision of the smart cities (related to the planning of personal mobility or the celebration of location-based urban games).

Appendix A. Reenactment script

A.1. Roles

The description given in the following subsections is ready to accommodate a varying number of reenactors, with a minimum of 6. At the very least, participants need to take up the following roles:

- Xerxes, king of the Persians.
- Leonidas, king of the Spartans.
- Ephialtes, the Greek traitor.
- Two soldiers for the Persian side.
- One soldier for the Spartan side.

If there were more than six participants, they may take the following additional roles (listed in descending order of importance):

- At least one Phocian (to try to monitor the Anopaeon path).
- More Persian soldiers (ensuring that there are never fewer Persians than Greeks overall).

- At least one Theban (of those who returned to their homes before the Persians' final ambush).
- More Spartan soldiers.
- At least one Tespians (of those who stayed until the end with the Spartans).
- Arcadians, Corinthians, etc.

A.2. Zones

The places corresponding to the markers on the floor of the room where the reenactors move around are the following ones:

- Asia Minor.
- Hellespont.
- Corinth (where the Greeks decided to go to war defending Thermopylae on land and Artemisium at sea).
- Sparta, Phocis, Thebes, Arcadia, etc. (starting locations).
- Thessaly (home of Ephialtes).
- Settlement of the Persian army at Thermopylae.
- Settlement of the Greek army at Thermopylae, beside the old Phocian wall.
- Location of the Persian onslaughts, the other side of the wall.
- Location in the Anopaeon path.
- Greek army rearguard.
- The sky of Elysium (for the Greeks who die and do not get new roles).
- The Tartarus (the Greek underworld) to accommodate Ephialtes if he dies.
- The Garothman (Zoroastrianism heaven, for the Persians who die).

A.3. The script of the battle

In collaboration with historians from FHW, we have defined a 4-act script for the battle considered in our REENACT approach:

- *Act 1*: the first act is a representation of the prelude of the war: advance of the Persian army from Asia Minor across the Hellespont, decisions of individual city-states on going to war and congress of Corinth (where it was decided to await the Persians at Thermopylae). While the Persians build a bridge to cross the Hellespont, Xerxes sends an emissary to try to convince the Greek city-states to surrender and join his empire. The emissary announces the Persian intentions at different city-states and finally goes to Sparta, where Leonidas can choose to kill him or not (which does not make any difference globally). The inhabitants of the city-states visited by the emissary, idle until then, vote whether to go to war or not, and if so send a representative to Corinth. There, Leonidas learns who will accompany him to Thermopylae. In the end, all the reenactors are located in the zones of their settlements at Thermopylae. Ephialtes does nothing in this act: he remains in Thessaly herding cattle and only in the end does he learn of the Persian advance after completion of the Hellespont bridge.
- *Act 2*: the second act is a representation of the first day of fights between Greeks and Persians, to illustrate that the knowledge of the terrain and the better weapons carried by the Greeks served to inflict unexpected damage to the Persian army, notwithstanding its overwhelming numerical superiority. The fight is staged to last a couple of minutes, after which the Persians, defeated, go back to their settlement and the Greeks, euphoric, go to theirs. While the carnage occurs, Xerxes is visited by Ephialtes and chooses to heed him ("that sounds interesting...") or to ignore and kill him ("this may be a trap..."). On the other hand, during the evening celebration, Leonidas learns of the

existence of the Anopaeon path and decides whether to send someone to protect it ("it's better to take precautions...") or not ("I do not think they will find it, and I need all Greek forces here"). The decisions of Xerxes and Leonidas will determine the happenings of the third act.

- *Act 3*: the third act is a representation of the second day of battling between Greeks and Persians, giving way to alternative endings that derive from the existence of the Anopaeon path and the choices of Xerxes and Leonidas. If Xerxes decided to ignore Ephialtes, he will have lost a great strategic advantage. This yields a way for the Greeks to win:

- If Leonidas did not protect the Anopaeon path, he keeps all the Greek forces with him and so manages to repel the Persian onslaught again, as in the second act. The reenactment continues by act 4A.
- If Leonidas sent the Phocians to protect the path, the Greek army will be weaker down in Thermopylae. Things happen like the previous day, but the Greek side will suffer far more casualties. The reenactment continues by act 4B.

If Xerxes decided to heed Ephialtes, half the Persian troops go with him to the Anopaeon path zone. Now there are two options:

- If Leonidas decided to protect the path, there will be a clash up there, in parallel with the struggle down in Thermopylae. The Persians win on the path and spend the night right there, while the Greeks win at Thermopylae, returning victoriously to their camp once again. The reenactment continues by act 4C.
- If Leonidas did not protect the path, it will be plain sailing for the Persians to move through it. Yet, the path is long, so they stay overnight. The reenactment continues by act 4C, like in the previous point.
- *Act 4*: here we consider 3 possible ends for the fight between Greeks and Persians.
- *Act 4A: Greek victory*: after two days of fruitless struggle in a quagmire, Xerxes is out of his mind, and his (self-attributed) condition of God-on-Earth makes him pick up a sword and go fight himself. He goes with all of its army, insisting on the error of the previous two days. Xerxes dies in the midst of the battle. The members of the Persian army, once their leader has been killed, give up and go back to their homes running towards the Hellespont. The Greeks, victorious, start jumping at Thermopylae. END.
- *Act 4B: Persian victory following a battle of attrition*: a third day of fights and Persian victory by brute force is represented. After everyone has reached the site of the fights, Thebans and people from other city-states may choose to flee, in which case they go back to their hometowns. Commanding an exhausted and reduced army, Leonidas falls in the end and the other remaining Greeks die after a while. Yet, many Persians die over one minute and a half, just for the statistics. Xerxes stays celebrating at Thermopylae, while his troops are sent to wreak havoc in different city-states of Greece. END.
- *Act 4C: Persian victory by appearing on the Greek rearguard*: this act represents the third day of battle with the Persian advantage of moving through the Anopaeon path. Right after starting a new attack on the Greek frontguard, half of the Persians come down the Anopaeon path and appear behind the Greeks, who remain completely surrounded. Thebans and people from other city-states are given the option to flee. The Spartans, however, are left to wait for death next to his king. The final attack is a massive

discharge of arrows. As in act 4B, Xerxes celebrates victory at Thermopylae while the Persian survivors are ordered to go to trample the city-states of Greece. END.

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