A mobile Augmented Reality system integrating 3D model and radiance scaling to enhance epigraphical inscriptions

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Abstract: The work is part of Aquae Patavinae project and it deals the enhancement and the recontextualization of Monte Venda's rupestrian inscription and Galzignano's and Teolo's boundary stones that marked the boundary line between Este and Padua territories. The artefacts are preserved in different museums, outside their territory; the main goal is to derive 3D digitization to recontextualize them in the context of the Museum of Thermalism which will be opened by Aquae Patavinae project in their provenance area. Furthermore, the work resolves other issues, related to interactive visualization and understanding of inscriptions, in the museum exposition, and in the images, used to publish and explain the results of archaeological and palaeographical researches.

The 3D digitization is performed through image-based survey, processing with Structure from Motion and Image Matching algorithms; the innovative approach permits to experiment different rendering modes that enhance epigraphic texts, details and damaged signs on the surface. Then, the dataset is implemented into a mobile and interactive Augmented Reality system where the digital contents are loaded in integrating the publication of epigraphic analysis. The user visualizes inscriptions and artefacts clearly, besides he accesses to more informative contents that enhance historical and palaeographical research, constituting an edutainment experience and favouring the dissemination of Cultural Heritage.

Keywords: Augmented Reality, 3D Digital Model, Radiance Scaling, Epigraphical Inscriptions

Introduction

The work is part of Aquae Patavinae project (GHEDINI et al. 2013), whose name derives from Latin authors and it indicates the Euganean thermal area (Fig. 1), located in the southwest of Padua city (northeast of Italy). Today, it includes Montegrotto Terme, Abano Terme, Torreglia, Galzignano Terme, Arquà Petrarca and Battaglia Terme. The project's goal is to study the thermal phenomenon and the settlement processes, related to it, from advance Roman occupation as far as present day. In this approach an enhancement system is planned with an information point at Terme Euganee/Abano/Montegrotto train station (Montegrotto Terme), several informative boards, related to visible and not visible ancient structures, a website[1] and finally the opening of the Museum of Thermalism, in Montegrotto Terme, whose project is ongoing.

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[1] http://www.aquaepatavinae.it

The paper presents the 3D enhancement of Monte Venda's rupestrian inscription and Galzignano's and Teolo's boundary stones, dated from 2nd century BC to 1st century BC and preserved in two museums, outside Euganean territory. The main aim is to group and enhance epigraphic finds in the same context,

Fig. 1 – Euganean Hills, in the northeast of Italy. The boundary stones marked the boundary line between Padua and Este territories.

located at the Museum of Thermalism. Besides, the work resolves other problems related to partial and not detailed visualization of objects, caused by their characteristics and arrangement in the museum exposition, and by limitations of traditional techniques, used to acquire the images, published in 1992 to explain the results of palaeographical and archaeological researches. The innovative methodological approach exploits the results of 3D digitization to experiment different techniques of rendering, based on shaded modes, like depth map and lambertian radiance scaling which provide a better visualization of inscriptions. Then, data are integrated into a mobile Augmented Reality (AR) system to enrich, in this case, the paper that publishes the results of archaeological and palaeographical researches (BUONOPANE 1992). As a consequence, new tools are returned to analyse and highlight epigraphic heritage and their semantic value as well as educational and entertainment experiences are carried out.

The depth map and different radiance scaling shading techniques enable to decipher and improve the visualization of surface features (BOZIA *et al.* 2014; GRANIER *et al.* 2012; HAMEEUW and WILLEMS 2011), and spatial AR systems project the results of phong radiance scaling mode on artefacts to enhance them in museum exposition (RIDEL *et al.* 2014).

AR derives from Human Computer Interaction field of research and it is part of serious games systems, used in cultural and educational contexts to carry out learning and entertainment experiences. It has long been experimented, before its dissemination, induced by wide spread of technologies, especially mobile devices. AR is an interactive and real time system, that simultaneously presents physical and digital elements, previously aligned and set up. It "adds" more contents, like images, texts, video, 3D model, audio, website, social network links, etc., on real scene, obtaining an immersive and educative experience.

The integration of different technologies in the Cultural Heritage framework is exploited to handle artefacts in their provenance context and to share them with other researchers, facilitating social and scientific

collaboration. ARCube System (JIMÉNEZ FERNÁNDEZ-PALACIOS *et al.* 2014) suggests a methodology to overcome scientific limitations connected to rotation and visualization of objects. Besides, AR systems integrate several techniques of communication (e.g. storytelling) to access informative contents in cultural pathways, historic centres, archaeological sites (PIETRONI *et al.* 2011) and inside museums (KEIL *et al.* 2013). Finally, AR is applied on books, constituting a system called AR pop-up book and a new learning experience, usable in different instructive contexts (GRASSET *et al.* 2008).
The system, dealt on this article, works on paper or digital books, but it is suitable to be exported inside museums, where informative contents will be loaded on real artefacts to carry out an edutainment visit.

Historical context and archaeological value

The first attendances and uses of the Euganean thermal sources are tied sacred exploitation in Montegrotto Terme and dated between second half of 7th century and 4th or 3rd century BC. After Roman occupation and during 1st century BC – 1st century AD, there is the first stable settlement and it is started to take economical advantage of natural resources including trachyte quarries, timber, inland waterways and terrestrial ways. The territory is been at the centre of a quarrel between Este and Padua, probably connected to the exploitation of natural resources and the three boundary stones are placed by roman senate to ratify the boundary line, ascribing the Euganean thermal area to Padua territory (Fig. 1).
The event is during the Romanization period and it proves the strong influence of roman senate that is called to establish the boundary line among local inhabitants and it uses the Latin language to express the resolution in an area where it is still diffuse the pre-roman language. Through the magistrate, cited on the inscriptions, the event is dated at 141 BC.
Epigraphists and archaeologists are very interested in the boundary stones and their inscriptions, probably engraved by different skilled workers, at two distinct moments (BUONOPANE 1992).
Monte Venda's rupestrian inscription (Fig. 2) has 2 incisions with the same contents. Venda A text, partially damaged, is on the upper part of the stone and presents an irregular style with a non-worked surface. Differently, Venda B, which is on the lower part, is more regular and the surface is prepared previously.
Galzignano's and 2 blocks of Teolo's boundary stones (Figs. 3, 4) have the same contents and some linguistic variants on the inscriptions. The first one has a longitudinal text, due to its truncated cone shape, and the epigraphic style is comparable with Venda B and Teolo B. The last one is on the littler block of Teolo's boundary stone, whereas Teolo A block has a longitudinal inscription, which is frequent in ancient local culture, and its palaeographic technique is similar to Venda A.
Probably Venda A and Teolo A texts are engraved by local skilled workers with irregular and local techniques, at the moment of the roman resolution, while Venda B, Teolo B and Galzignano inscriptions might constitute a rewrite, carried out by outside skilled workers with regular technique and dated by the beginning of 1^{rs} century BC. This one could be connected to a restoration of roman resolution, due to the Cimbri invasion that causes new disputes among local inhabitants, related to boundaries of territory.
Today, Monte Venda's rupestrian inscription and Galzignano's boundary stone are exposed at National Atestino Museum in Este (Padua) and the Teolo's boundary stone is preserved at warehouse of Eremitani Civic Museum of Padua.

Figs. 2, 3, 4 - Boundary stones. 2) Monte Venda's rupestrian inscription, exhibited at National Atestino Museum in Este (high 1,232 m × width 0,95 m × depth 0,36 m). 3) Galzignano's boundary stone, exhibited at National Atestino Museum in Este (high 3,24 m × diameter 0,629 m). 4) Teolo's boundary stone, preserved at warehouse of Eremitani Civic Museum of Padua (Teolo A, large block, 0,90 m × diameter 0,64 m; Teolo B, little block, high 0,49 m × diameter 0,50 m). (Copyright: Italian Ministry of Cultural Heritage and Activities and Tourism [2, 3]; Padua Municipality – Councillorship Culture and Tourism [4])

3D data survey and processing

The 3D digitization is performed with reality-based approach that returns accurate and detailed x, y, z and RGB data. An image-based technique is chosen to follow the same principles of photogrammetry, automated through computer vision procedure (VERHOEVEN 2011; GUIDI *et al.* 2013). The choice derives from the surface characteristics, the objects dimension, the scale of restitution, the arrangement in the museum and the environment conditions.

The goal is to obtain a 1:1 representation of each object; this derives that average Ground Sample Distance (GSD) is 0,2 mm and the distance between lens and surface is approximately 1 m, due to technical characteristics of digital reflex cameras used: Nikon D5000 and Nikon D3200 (Tab. 1).

The first one is chosen for its movable LCD screen that favours the survey of surfaces, with a poor access inside Este Museum, and where the illumination of room and the objects provide some problems. The second one returns higher quality data and was used to survey the Teolo's stone blocks in a shaded area.

The survey procedure acquires the shape from different points of view, using orthogonal and oblique images. This approach resolves some problems due to the illumination coming from lateral sources too and to operator's mobility caused from physical obstacles around the objects.

Models / **Specs**	**Nikon D5000**	**Nikon D3200**
Body type	Compact SLR	Compact SLR
Sensor type	CMOS	CMOS
Sensor size (mm)	APS- C 23,6 × 15,8	APS-C 23,2 × 15,4
Sensor resolution (Megapixel)	12	24
Max size of frame (pixel)	4.288 × 2.848	6016 × 4000
Lens	AF-S DX NIKKOR 18-55 mm f/3.5 -5.6G VR	AF-S DX Zoom - NIKKOR 18-55 mm f/3.5 -5.6G ED II

Tab. 1 – Nikon D5000 and D3200 technical characteristics.

Data pre-processing, performed through Adobe Photoshop CS5 Extended[2], verifies the images quality, chromatic homogeneity and neatness. Then, the processing uses a semi-automatic approach with Agisoft Photoscan Professional[3]. Multiple and convergent acquisitions are aligned through Structure from Motion (SfM) algorithm to derive the internal camera parameters, camera positions and geometry of 3D scene (Fig. 5). The user sets the accuracy parameter and control points; then a sparse and not structured point cloud is returned. The result is scaled, through a reference length, acquired in at least a couple of images, and finally it is optimized. Successively, a dense multi-view stereo matching algorithm returns a dense and structured points cloud on which the user sets up levels of resolution and depth maps. Meshes and textures are so processed, considering the object characteristics and preserving the geometric and radiometric accuracies. Very large datasets are divided in many groups: Photoscan aligns and registers the so-called chunks and Geomagic Studio[4] merges them.

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[2] http://www.adobe.com

[3] http://www.agisoft.com

[4] http://www.geomagic.com.

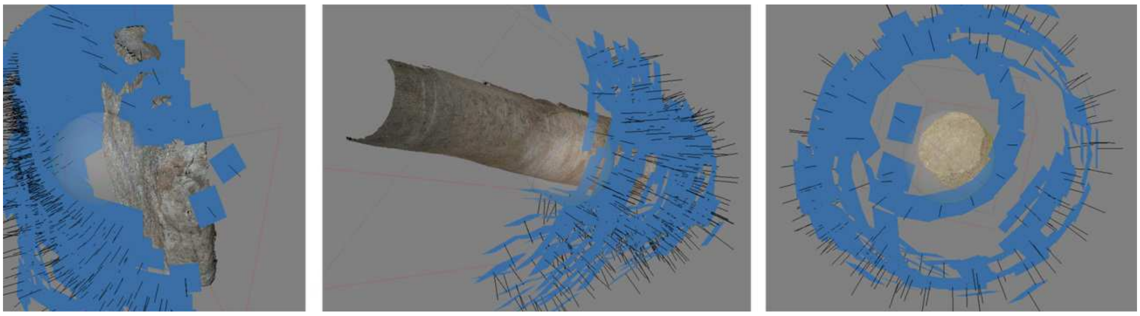

Fig. 5 – Point cloud of boundary stones and camera position. From left, Monte Venda's rupestrian inscription, Galzignano's boundary stone and block B of Teolo's boundary stone. (Copyright of raw images: Italian Ministry of Cultural Heritage and Activities and Tourism; Padua Municipality – Councillorship Culture and Tourism)

Techniques of visualization

A 3D textured polygonal model of each boundary stone is obtained (Fig. 6), with millimetre Level of Detail (LoD) resolution (Tab. 2), besides metadata and paradata are collected to document the work and to support other uses of datasets.

The digital objects are managed entirely, in terms of visualization and handling, overcoming difficulties connected to their shape, dimension and arrangement in the museum and to images acquired with traditional techniques; other problems came from irregular inscriptions and bad state of conservation. Hence, automatic procedures, available in several software packages as Meshlab, 3D Studio Max and Rhinoceros[5], are used

Artefacts / Data	Monte Venda's rupestrian inscription	Galzignano's boundary stone	Block A, Teolo's boundary stone	Block B, Teolo's boundary stone
Format	x, y, z RGB	x, y, z RGB	x, y, z RGB	x, y, z RGB
Images	1076	717	345	204
Polygons	2.635.104	2.946.770	1.914.580	906.934

Tab. 2 – Data, images and polygons from 3D survey.

[5] http://www.meshlab.sourceforge.net; http://www.autodesk.it/products/3ds-max/overview; http://www.rhino3d.com/it.

Fig. 6 – The boundary stones 3D textured models. (Copyright of raw images: Italian Ministry of Cultural Heritage and Activities and Tourism; Padua Municipality – Councillorship Culture and Tourism)

to select and group faces of 3D surfaces with the same morphological trend, favouring the individuation of damaged features and the depiction of irregular inscriptions.

Different techniques of visualization, based on shaded modes, are experimented in Meshlab to enhance the surface morphological details.

The grayscale depth map mode highlights concavities, through illumination or shade, where the intensity of pixel depends on depth of the signs (Fig. 7). It doesn't return homogeneous results on the entire surface; to improve the visualization on different areas, the parameters must be modified. The lambertian radiance scaling mode (VERGNE *et al.* 2010) is tested to simulate an ideal lambertian surface, where the light is reflected uniformly, basing on the material and the angle between the surface and the direction of the light source itself (Fig. 7). Radiance highlights concavities and convexities on the surface, through brightness and shading, to enhance geometric details and feature variations. The intensity of pixel increases simultaneously with depth of signs, facilitating their individuation; the visualization is homogenous on the entire model, and the depiction of each damaged feature is provided, highlighting its semantic value.

Furthermore, the limitations of traditional approaches are overcame and more objective and accurate representations are returned, favouring palaeographical and archaeological analysis. Finally, these renderings work in real-time, are exportable to other systems like AR, enhance the morphological details and are suitable on low-cost mobile devices too.

Fig. 7 – Different techniques of visualization of Venda A inscription: from left 3D textured model, depth map and lambertian radiance scaling. (Copyright of raw images: Italian Ministry of Cultural Heritage and Activities and Tourism)

Mobile and interactive AR system

Different hardware approaches for AR are available: installations and mobile systems (AZUMA *et al.* 2001). The first ones use a display that embeds a camera to track the real scene and the references; the digital contents are loaded, whereas the projection display projects data directly on physical objects. The second ones run on mobile devices (LEUE *et al.* 2015), like the near-eye display or head-worn display, e.g. Google Glass or Epson Moverio BT-200[6] and on small hand-held display, like smartphone and tablets. The last one has several advantages, connected to wide diffusion of personal technologies in daily life and an intuitive and interactive user interface that determines an immersive and entertainment experience, accessible everywhere.

Generally, for inside pathways, systems track 2D marker (Quick Response Code – QR code), 2D markerless (standard images) and 3D markerless (based on CAD data), which add digital contents on real objects.

In outside environments, the location is tracked through Location Based Services (LBS) on GPS/GLONASS based mobile devices that acquire the viewer position and information at Points Of Interest (POI).

A 2D markerless tracking system is presented, working with any printout or digital picture featuring visual elements with a good contrast. The chosen images of boundary stones are published in the proceedings of Conference, held in 1989, where the results of archaeological and palaeographical researches are explained (BUONOPANE 1992), highlighting the semantic importance of inscriptions and their connection to historical context. Such images don't return a very detailed depiction of inscriptions and they don't favour their understanding. Hence, AR system is used to integrate and load 3D textured model and the lambertian radiance scaling rendering on standard images. The user is able to compare the contents of article with digital data that simulate the real objects and to visualize the render and video-render with enhanced inscriptions. The epigraphic texts are associated according to their chronology and palaeographic techniques of realization, as well their relationships, historical contexts, and semantic values are highlighted.

[6] http://www.google.com/glass/start; http://www.epson.co.uk/gb/en/viewcon/corporatesite/products/mainunits/overview/12411.

Overview of setup system

The system is based on an optical tracking configuration and it works using the camera of mobile device and loading digital contents, previously aligned with images.

The realization and the organization of media contents (Fig. 8) require long time and hard work, besides the collaboration among technicians, historians, archaeologists and educators is mandatory to manage cultural heritage and to focus the attention on objects visualization as well their semantic meaning, relationships and contexts.

The test case uses a decimated 3D model (low-poly-model); current mobile devices aren't able yet to manage and to render high-poly-models and textures larger than 2048 × 2048 pixel. This application, based on iPhone 4S performances, uses 3D .OBJ models, composed by 55.000 polygons as maximum and texture not larger than 1024 × 1024 pixel.

Therefore the surface details and the real object simulation are returned through textures (Fig. 9). Finally, lambertian radiance scaling rendering and video-rendering are integrated to enhance damaged features and inscriptions.

Fig. 8 – Teolo's boundary stone image from Buonopane's article, used as a marker. (Copyright: BUONOPANE 1992)

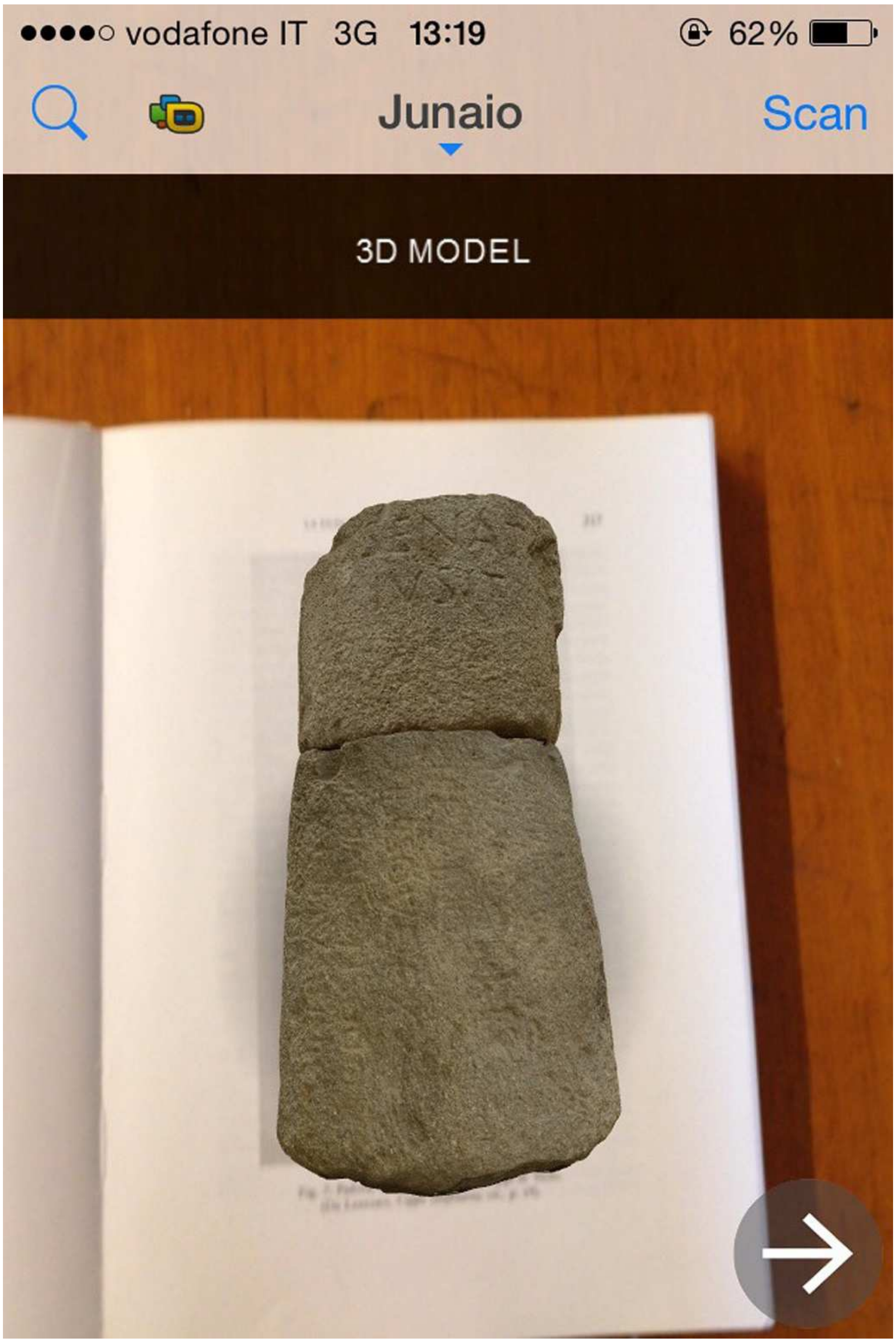

Fig. 9 – Teolo's boundary stone textured model, returned through AR system on standard image. (Copyright of raw images: BUONOPANE 1992 and Padua Municipality – Councillorship Culture and Tourism)

Metaio Creator to perform the configuration and Junayo AR browser App to visualize contents are chosen[7]. The workflow is divided in scenes, where real elements, constituted by published images of boundary stones (Fig. 8), and the described digital contents are aligned. Some parameters must be set up to return a better

[7] http://www.my.metaio.com/dev.

and stable depiction, to connect animation and to get the best video resolution. Finally, the layout is stored in a personal cloud server, accessible and viewable only by the user through Junayo AR browser App.

The interactive interface

The system works with paper and digital pictures; in demo mode, it is connected to the cloud server through QR Code (FONSECA *et al.* 2013). The viewer reads the article and uses the smartphone to scan and recognize the three images, used as markers; several contents are loaded and divided among the interactive scenes, managed by user through virtual buttons. The first one presents 3D textured model of each object and the user moves it and zooms in. Hence, the visualization is improved and contents of publication and 3D data are compared simultaneously.

Furthermore, the two blocks of Teolo's boundary stone realize a more enjoyable experience, where the viewer experiments their alignment and spatial division, according to their ancient relationship as hypothesized by epigraphists (Fig. 10). So it is possible to depict the real appearance of boundary stones and their state of preservation and/or use different visualization modes and contents to highlight morphological details, feature variations on the surface and semantic values.

The second one presents lambertian radiance scaling rendering of Monte Venda's rupestrian inscription and Galzignano's boundary stone, enhancing the epigraphic texts. A static rendering isn't sufficient for the Teolo's boundary stone, because the inscriptions are engraved on almost the entire circumference of artefacts; therefore, a video-rendering for each object is used distinguishing the two blocks and reading the epigraphic texts entirely, in video frames succession.

Finally, it is possible to compare the Monte Venda's rupestrian inscription with Venda A and Teolo A rendering and to explain their historic meaning, relationship and the palaeographical techniques (Fig. 11). The Galzignano's boundary stone, associated with Venda B, Galzignano and Teolo B rendering, illustrates the rewrite of texts and the events connected to it.

Discussion

The integration of different depictions and digital data into an interactive and real time AR system supports scientific research and it constitutes an edutainment experience that exploits the wide spread of technologies to propose new methodologies of analysis, enhancement and dissemination of cultural heritage.

In this paper they are applied to the boundary stones and the results of their archaeological and epigraphic studies. The system relates and distinguishes media contents and reality, it sets and groups artefacts, basing on their historical and palaeographical values and it carries out a personal, immersive and educative pathway that the user follows according to his preferences. Besides, he is enabled to take a screenshot at the moment of his favourite scene to share through printing, social network links and web services. Finally, the low-cost and widespread technologies can determine the success of system thank to the multi-user access.

Fig. 10 - Interactive sequence on Teolo's boundary stone AR application. The user moves 3D textured model and he reads the image caption, besides he experiments the relationship between two blocks, living a more enjoyable experience. (Copyright of raw images: BUONOPANE 1992 and Padua Municipality – Councillorship Culture and Tourism)

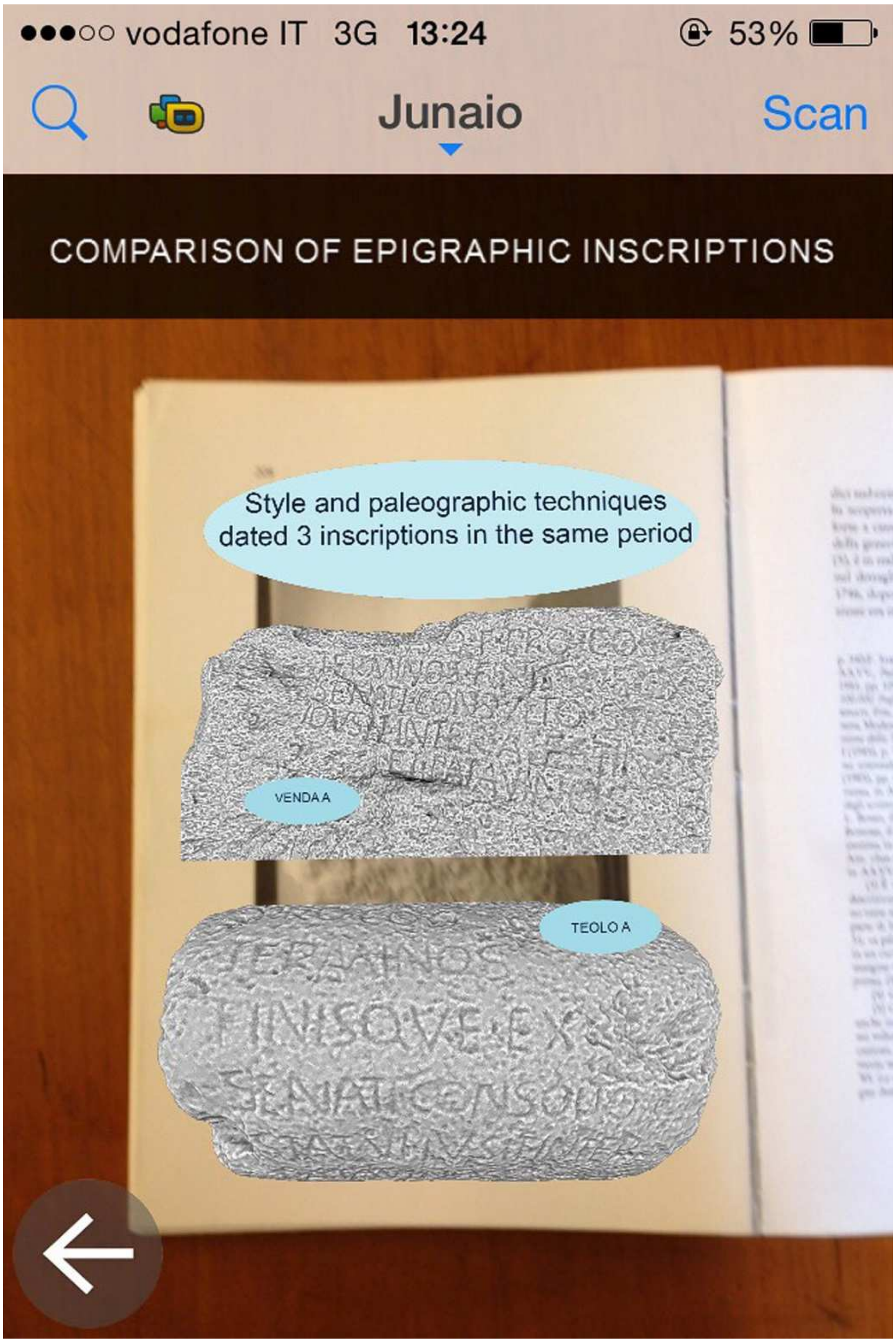

Fig. 11 – Monte Venda's rupestrian inscription. The interactive scene depicts Venda A and Teolo B inscriptions, enhanced by the shaded mode. The texts are compared and explained by informative labels. (Copyright of raw images: BUONOPANE 1992; Padua Municipality – Councillorship Culture and Tourism; Italian Ministry of Cultural Heritage and Activities and Tourism)

The active user must take in account some troubles. The first one derives from environment condition because strong sources of light return issues of visualization, besides a distance longer than 20 cm, between camera and marker, is recommended to provide data correctly and stable depictions. The respect of these parameters requires the user awareness of the interactive approach and the contents, determining his active role and motivating him to follow the cultural pathway, where an enjoyable, worthwhile and learning experience is carried out.

Others shortcomings are related to current performance of devices that manage low-poly-3D models, textures not larger than 2048 × 2048 pixel and not rotating 3D data. If a partial return of the inscriptions engraved on almost the entire circumference is got, dynamic contents like video rendering of lambertian radiance scaling are loaded, to provide a complete visualization and enhancement.

Conclusion and future work

AR systems have a great potential in the Cultural Heritage framework because they provide entertainment and learning experiences and highlight a clear separation between virtual and real worlds. Furthermore, AR works outside and inside with mobile devices too, relating different situations and contexts, adding analogue and digital data (e.g. spatial coordinates) on physical elements (papers, books, objects, etc.). Focusing the attention on contents and their organization, exposition and coherence with objects is mandatory.
The integration of 3D model and lambertian radiance scaling visualization into AR system is proposed as experimentation, but this interdisciplinary approach is suitable to support edutainment aims. The contents are interoperable with other AR systems (e.g. 3D markerless based on CAD data tracking) and they are suitable in different environments, like museum, archaeological sites and educational workshops, providing a wider dissemination of results and awareness. New applications will return more results, enhancing the cultural heritage, its relationship with different contexts and different artefacts located in different places. Nowadays, there are educational technologies that takes advantage of serious game applications to improve traditional learning techniques and cultural pathways, explaining the analytical methodologies, combining digital data and physical objects and using interactive interfaces that carry out a personal and emotional experience. Finally, the user has an active role and can realize immersive pathways with social and collaborative experiences.

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