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Original article

Access to complex reality-based 3D models using virtual reality solutions

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ABSTRACT

Cultural Heritage is a precious resource that witnesses our past and that should be transmitted to future generations. The creation of digital 3D representation of monuments and sites have been demonstrated to be a reliable method for preservation and historical purposes. In order to preserve a high level of detail, the reconstructed point cloud will typically contain millions of points, which could result in several GB of data when stored on disk. For these reasons, a challenge for the scientific community is to find new ways to visualize and disclose 3D digital contents, obtaining a better access and communication of the Cultural Heritage information. In this paper, Virtual Reality (VR) devices are employed to provide not only a simple visualization but also an immersive experience for digitally reconstructed heritage scenarios. Oculus Rift (VR visualization headset) and Kinect (depth sensor for user interaction) are integrated in order to interact and navigate in a complex 3D or 4D (temporal) archaeological scene as well as to have access to digital media contents of several MB of size. In this way, archaeological sites or fragile environments with forbidden access due the preservation policies can also be virtually visited and inspected.

Research aims

The paper presents a visualization pipeline developed to exploit and access large and complex heritage 3D contents in an easy and interactive way through VR methodologies. In particular the work focused on (i) visualizing and managing complex reality-based 3D models with a real-time fluent interaction, (ii) investigating the integration of specific VR devices – such as Oculus Rift and Microsoft Kinect – for heritage applications and (iii) offering to the scientific community, as well as common users, an innovative way to promote the knowledge of Cultural Heritage sites.

1. Introduction

Nowadays, the incessant development in the field of 3D recording techniques together with the latest technological progress in hardware, software and digital content delivery allow the remote exploration of complex archaeological sites and monuments. Actual reality-based 3D surveying techniques like laser scanning [1] and photogrammetry [2] are currently able to produce precise, detailed and photo-realistic 3D digital representations useful for documentation, archaeological and architectural analyses, visualization, divulgation and educational purposes, museum exhibitions or virtual tourism. According to the location, dimension and complexity of the heritage sites as well as the project goals, these 3D methodologies are very often combined exploiting the intrinsic advantages of each technique [3–8]. In a reality-based 3D digitization project, the main goal is to produce an accurate and photo-realistic digital replica of the surveyed reality, considering not only the specifications of the desired output (e.g. 3D models or other suitable representations) but also cost's and execution time's minimization. The design and realization of such activities require not only expertise in several disciplines but also the knowledge of the employed sensors as well as the understanding of the application and its environment. According to [9], the steps for a reality-based 3D digitization project are:

a. Site overview (or object examination) and planning.
b. Selection of the appropriate 3D surveying and recording technology and parameters (or a combination of multiple technologies).
c. Data collection after positions planning and configuration design.
d. Data acquisition workflow based on best practice.

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e. Selection of data processing tools, 3D model representation method and suitable file formats.
f. Selection of software tools able to handle processing and visualization requirements.

Following this workflow, detailed 3D models are normally generated, consisting of millions of polygons and high resolution images, making them very "heavy" and difficult to be handled by common computers. In fact, despite technological developments, the management of large polygonal datasets can be limited by several technical problems, i.e. very long processing and editing time or real-time visualization constrained by the graphics card performance. Computer performance is highly needed otherwise it is necessary to reduce the final size of the models in terms of geometry and textures. From a geometric point of view, it is possible to reduce the number of vertices and optimize the geometry [10]. In addition, in order to maintain a high quality visualization and not to miss geometric details for studies and analysis purposes, normal and displacement maps can be used [11–13]. From a radiometric point of view, it is possible to reduce and compress the high resolution images or, if necessary, a single texture can be generated for each model [12]. In all cases, it is necessary to find a compromise between accuracy, size and visualization of the 3D model. The scientific community continuously looks for new ways to document, visualize, study, manage and divulge digital replicas of Cultural Heritage sites without losing quality or information. In particular the focus is now towards new solutions in the field of Virtual, Augmented and Mixed Reality to find reliable ways to share, access and communicate the outcomes of a 3D digitization projects.

New ICT (Information and Communication Technology) technologies are quickly advancing and they allow different ways to access digital 3D information. Informatics resources are being exploited to create new platforms, applications and systems, with the aim of managing complex reality-based 3D models in real-time. Web-based platforms have been developed to visualize, study and manage them, for research and dissemination purposes without installing specific software [13–16]. Virtual Tours (VT) applications [17] allow the user to visit and explore heritage sites through a predefined path of panoramic images, supporting also digital media contents such as texts, documents, images, as well as sophisticated 3D models. Augmented Reality (AR) applications [18] allow to integrate and interact with this kind of 3D models into a real-world environment, through computer-generated sensory inputs (images, video, GNSS, etc.). 3D reconstruction can be applied not only to existing archaeological sites, historical buildings and artefacts but also to recreate environments. Virtual Reality (VR) is an immersive multimedia technique which replaces the real world with a virtual one where the physical presence is simulated [19,20]. In addition, Mixed Reality (MR) combines both the virtual world and the real world in order to create new environments where digital and physical objects coexist [21].

As a consequence, in order to exploit new resources and technologies, as well as to valorize and divulge Cultural contents, VR has been tested to create an immersive and reality-based virtual world, taking advantage of accurate 3D models. VR is a technological system that generates scenes and virtual representations that can be visualized by the user in a CAVE or through Headset Mounted Display (HMD), such as Oculus Rift VR [22–24], Samsung Gear VR [25], Neo Pro [26] or Project Morpheus (today known as Playstation VR), the Sony VR headset [24]. Also, thanks to low-cost supports as Google Cardboard [27] or OpenDive [28,29], smartphones can be used as virtual headsets. These technologies can be exploited to recreate the user's head movements in real time. Moreover, it is possible to capture whole user body movements using several devices, projecting real movements into the virtual world and enhancing self-awareness. Among them, we can find different kinds of devices: (i) deep sensor for user interaction such as Kinect [30–32], Structure [33], Leap Motion [34], etc., (ii) gloves equipped with sensors [35] designed to simulate the perception of different stimuli such as Control VR [36], (iii) bracelets [37,38], etc. In this way, VR allows the user to fully immerse into and interact with a virtual world.

The vast growth of computer performances (especially of graphics cards) has allowed the combination of new display technologies – such as VR tool – with 3D models in order to provide a better understanding of phenomena or facts by its 3D simulation and interaction with specialized equipment. VR can be applied to several daily life activities, such as gaming, entertainment and education but also industry-related applications, including engineering and telecommunications [39]. VR can help engineers to visualize different technical solutions in a 3D environment. VR can be also applied to fields where safe training is required, such as in medicine, (especially surgery and neurology) [40], in military contexts and in emergency situations (flight simulators) [41,42]. These new technologies play an important role in museums to recreate different epoques and give the possibility to explore them again [43–45]. VR is paving the road to a new and exciting way to communicate information, where the user is completely immersed in an interactive world. For instance, Europeana (a multi-lingual online collection of millions of digitized items from European museums, libraries, archives and multimedia collections) experimented VR technology, together with ArchiVision (a Dutch design agency). They developed a virtual museum ("The museum of the future") where a user can play with masterpieces from the Dutch Rijksmuseum [46]. The V-Must project (Virtual Museum Transnational Network) aimed to provide tools and support to develop virtual museums with communicative and educational purposes. They used VR technologies and devices for the exhibition "Keys to Rome, The City of Augustus", where the focus was the Augustan age. Companies like ArcTron [47] or ETT [48] are beginning to include VR applications exploiting the Oculus Rift technology among their products. Research centres and universities [18,49] are also involved in using VR for heritage applications.

2. Developed pipeline

The workflow is based on the Unity game engine coupled with natural interface devices to create a VR application able to visualize and disclose digitized Cultural Heritage properties to any user. Several case studies have been performed (Section 3), using 3D datasets surveyed with laser scanning and photogrammetry, in order to test the reliability and replicability of the VR methodology under different operative conditions. The pipeline manages detailed 3D models without losing quality, in terms of geometry and textures, with a fluent real-time interaction. This is a mandatory requirement to fully exploit all the contents of a 3D modelling project for visualization, communication, analyses and educational purposes. An intuitive interface was implemented where the user, assisted by the tracking system of the Oculus Rift headset, can obtain the model metadata. This methodology, coupled with Kinect, allows also to obtain complete control of the user's body movements.

2.1. VR implementation and devices

The implementation of the developed architecture (the hardware used to visualize and manage the data) (Fig. 1) merged open-source software/script and proprietary software. In particular Unity (3D engine) and OpenNI (Open Natural Interaction) were employed. Unity is a commercial game engine application that allows fast implementation time and the management of external devices for the integration of the user's body movements during

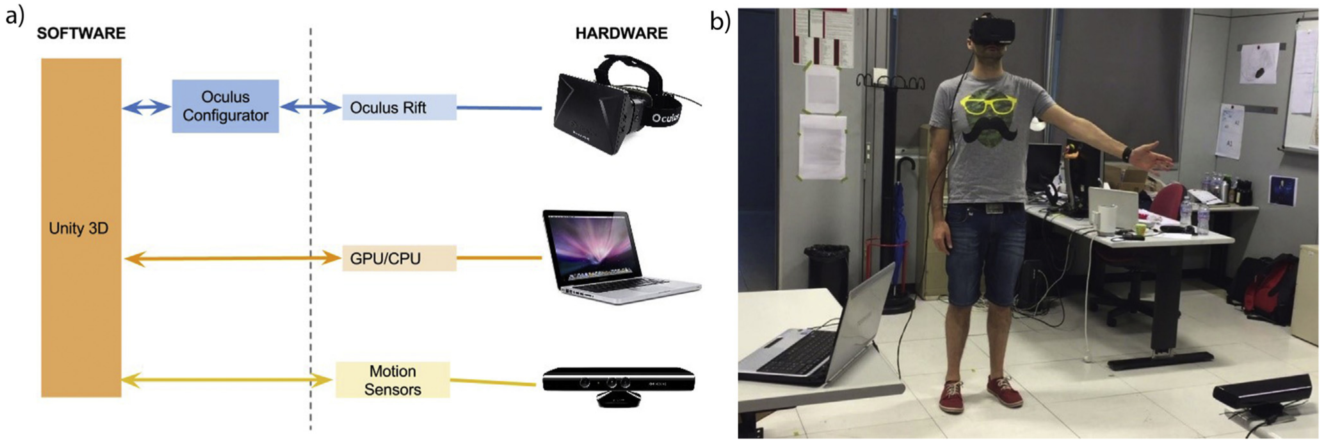

Fig. 1. (a) Software and hardware layers of the experimental architecture: a laptop (GPU: Intel HD4000 – 1 GB RAM, CPU: Intel Core i5 2.5 GHz – 4GB RAM) controls Kinect and Oculus Rift devices through Unity engine and related wrappers. (b) The set-up of the developed procedure: the Oculus device for the immersive visualization and the Kinect sensor to observe the body movements and activate multimedia contents.

the visual simulation. OpenNI is an open source software project focused on certifying and improving interoperability of natural (as well as organic) user interfaces, i.e. devices that capture body movements to allow a more natural interaction of users with computers.

From a hardware point of view, the set-up integrated an Oculus Rift and a Microsoft Kinect. Oculus Rift is a VR headset designed specifically for video games to make the gaming experience more immersive. Thanks to its hardware, Oculus Rift allows to replicate the natural movements of the user's head, increasing the perception of the user within the VR environment. Three important features make Oculus Rift (Development Kit 2) a very powerful and valuable device for VR applications: a display (960×1080 per eye), an internal tracking (accelerometer, gyroscope and magnetometer) and a viewing optics (100° nominal field of view). On the other hand, the Microsoft Kinect device was used given its flexibility, low-cost, portability and acquired experience with past projects. Kinect is a motion sensing input device used for video games and created by Microsoft. This device is composed by an RGB camera, IR depth sensor, motorized tilt function, a multi-array microphone and custom processor running proprietary software and it can be used to make applications thanks to software developer kit by Microsoft and OpenNI library. It allows the user to take remote control of the application, in an interactive way, from a distance that ranges between 0.8 and 4 m. Comparing to the other available low-cost solutions, Kinect is able to track and reconstruct full and partial markerless skeletal with a discrete precision, it has a good working range and it can be easily integrate with other sensors/devices.

In order to design a user-friendly interface, Oculus Rift and Kinect were tested with different kind of people (from children to adults). Based on the performed tests, the most natural and intuitive movements were chosen. Using Oculus Rift, the head movements allow the user to take control of the application (to obtain information, to change 3D scene, etc.). On the other hand, the Kinect sensor should only control the movement of the user's body into the VR scene. This is possible only when the user remains into the Kinect's field of view. The user will be able to walk forward through a slight thrash and respectively rotate (clockwise or counter-clockwise) by a slight movement of his right or left arm.

The two devices were integrated using OpenNI inside Unity, implementing an interaction process between the user and the digital contents. This method exploits a pointer centred in the main camera (Oculus Rift developed interface) and moves according to the head movements. The pointer is similar to the mouse pointer and it allows the visualization of visual contents. Invisible hot spots were placed in different points of interest. Once the user looks at a specific part of the virtual scene (named "hidden hot-spots") the access to the information becomes visible. The method is able to control these hot-spots and, depending on the pointer position, it also controls if the contents should be displayed or not (Fig. 2).

3. Case studies and results

Different digital 3D datasets have been used to test and assess the suitability and performance of the developed VR visualization application and to consider the potentiality of the presented methodology. For these purposes, various reality-based 3D models have been chosen based on their variety, in terms of dimension, shape, material, colour and size. In particular, we considered 3D models of various Etruscan tombs composed of multiple frescoed chambers. The used 3D models were produced collecting data through accurate 3D recording techniques such as laser scanning and photogrammetry (see [50,51] for more technical details). A Leica ScanStation, Time-of-Flight (TOF) terrestrial laser scanner (TLS), was used to acquire geometric data. This geometric data was recorded from different positions in order to survey the areas of interest with an average sampling step of 3–5 mm. The obtained unstructured point clouds were cleaned and aligned in a common reference system, followed by the generation of the final structured polygonal 3D models. The produced surfaces were edited and optimized, removing redundant data and merging together all the vertices within a specified threshold (tolerance). In addition, in order to create photo-realistic 3D models, a Nikon 3DX camera with fixed lenses (Nikkor 24 and 50 mm) was used to acquire high resolution images.

According to the complexity of the objects and the final purposes, the TLS 3D models were textured using different approaches: (i) panoramic and normal images were mapped onto the reconstructed 3D geometry of the painted chambers through photogrammetric techniques whereas (ii) virtual textures were used to realistically reproduce materials (e.g. *tufo*) in specific areas of the heritage sites. Furthermore orthophotos and rectified images showing virtually restored frescoes were used to map damaged areas and create hypothetical reconstructions ("virtual restoration)". The resulting photo-realistic 3D models are composed by millions of polygons and high resolution images, with a file size (in OBJ format) ranging from 200 MB to 700 MB (Fig. 3 and Table 1). Due to the huge size of the 3D models and the hardware used the upload time can be too long. In addition, a small delay can be noticed which could affect the fluidity of the 3D scene. To avoid this, the

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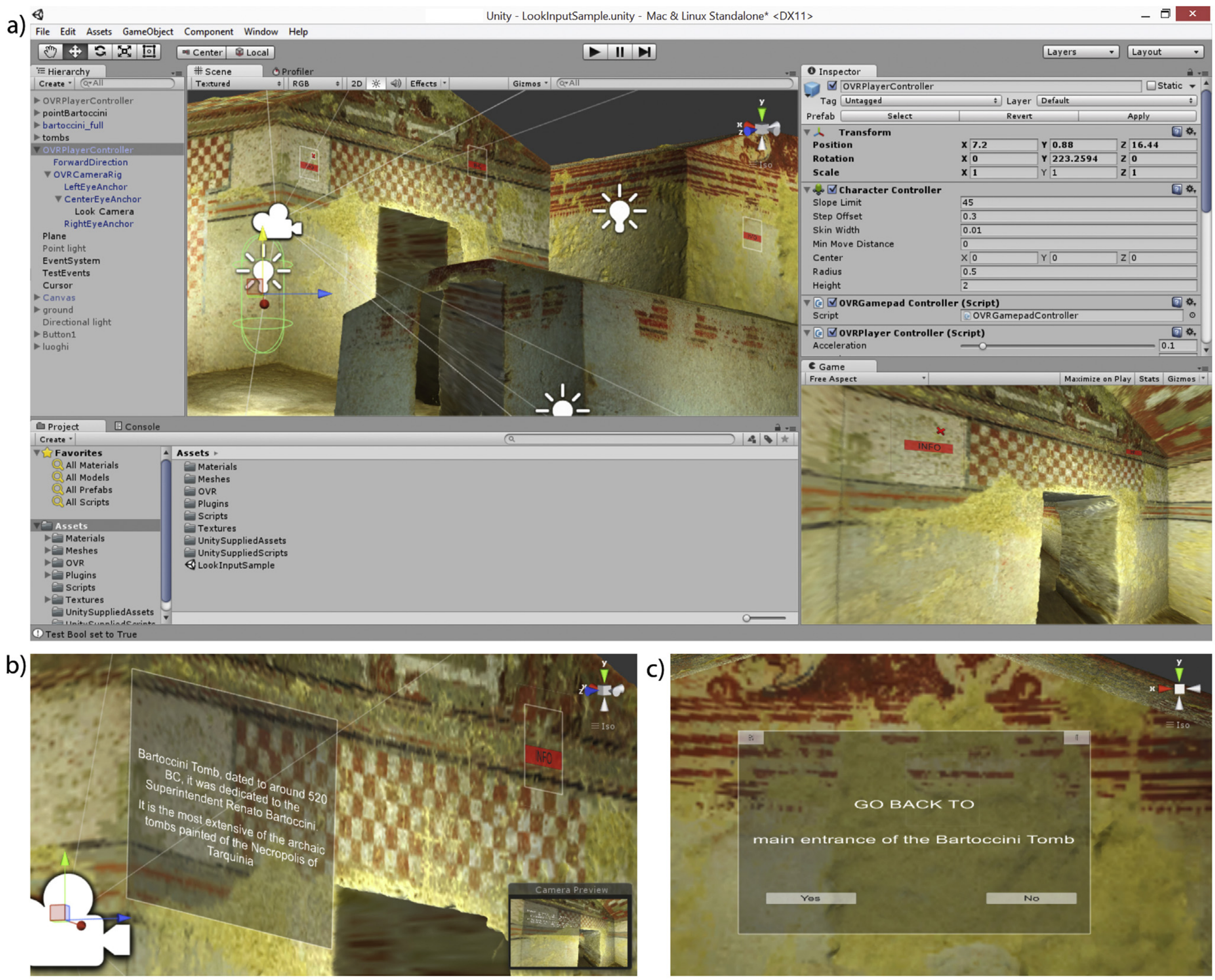

Fig. 2. A typical workspace inside Unity: (a) workspace for digital content visualization and data interaction through Oculus Rift, (b) retrieval of historical data information and (c) scene change.

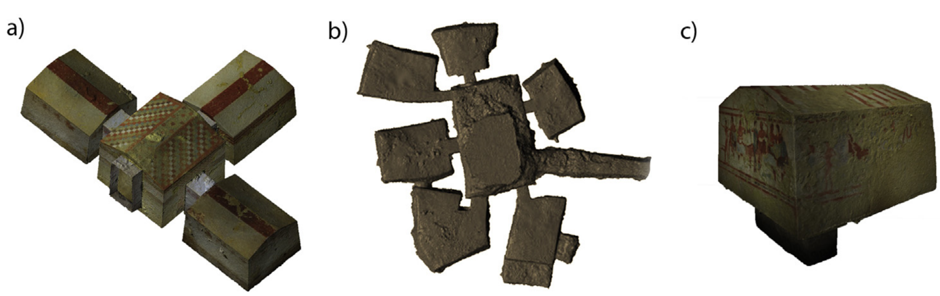

Fig. 3. Cases studies: 3D models of the (a) Bartoccini tomb, (b) Inscriptions tomb and (c) Bettini tomb.

Table 1
Characteristics of the employed 3D models. The uploading and visualization delay of the optimized 3D model depends on the employed hardware.

	Bartoccini	Inscriptions	Bettini
Period of the heritage site	VI cent. BC	IV-II cent. BC	V cent. BC
Location of the heritage site	Tarquinia (Italy)	Vulci (Italy)	Tarquinia (Italy)
Dimensions of the site	4 rooms, 44 m^2	7 rooms, 90 m^2	1 room, 12 m^2
Num. of polygons	ca 3 millions	ca 5 millions	ca 2 millions
Size of the original 3D model (including texture)	ca 520 MB	ca 700 MB	ca 200 MB
Num. of polygons (reduced model)	ca 450,000	ca 750,000	ca 300,000
Size of the optimized 3D model (including texture)	71.4 MB	92.7 MB	53.1 MB

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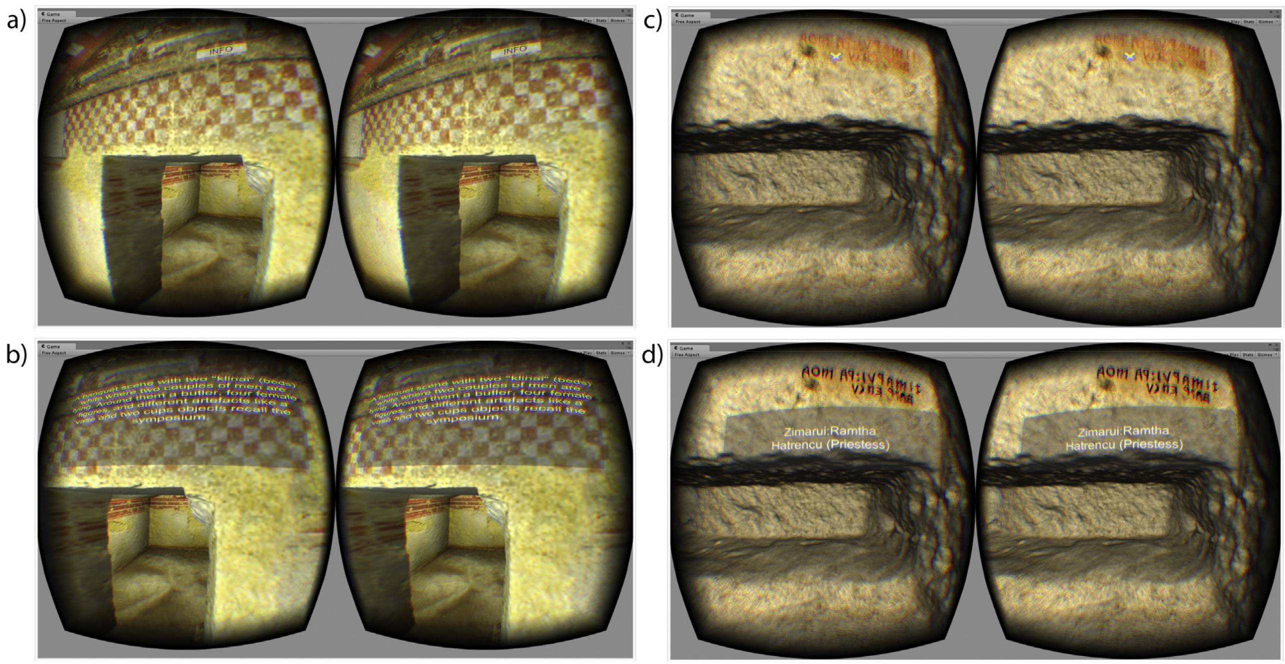

Fig. 4. Two examples of the VR application seen through the Oculus eyes: (a) the Bartoccini tomb with (b) a hotspot to text information and (c) the Inscription tomb with (d) a view to an engraving and its translation.

Fig. 5. (a) The current condition and (b) the virtual restoration of the frescoes in the Bettini tomb based on iconographic studies and historical information. The VR application for the immersive and real-time access to the Bettini digital 3D model: (c) the 3D model seen in the Oculus eyes, (d) the developed user interface to change scene and (e) the access to the virtual restoration of the frescoes.

Fig. 6. The VR application deployed for the immersive access of the Paestum Virtual Tour: (a) access to the Basilica monument, (b) internal view of the Basilica and access to the additional media content and (c) historical information. (d) Users enjoying the immersive VT with the Oculus headset during the 2015 EU Research Night.

final photo-realistic 3D models were reduced using different optimization techniques. It could be possible to reduce drastically the 3D data by CAD modelling but this involves the loss of complex surface details. Normal maps were used to optimize the geometry without losing visible quality [13]. To achieve a reduction the number of faces, the mesh of the reality-based 3D models have been optimized (using the "ProOptimizer" tool in 3ds Max), from high to low resolution. The texture mapping was preserved and the material information was maintained in the optimized polygonal models. Then, the geometry of the high resolution 3D models detail were projected onto a low resolution 3D models through normal maps (using the "Render to Texture" tool, in 3ds Max). In this way, it was possible to maintain the visual appearance at high resolution, reducing the weight of the 3D models. In the other hand, unwrapping techniques were used to obtain singles texture and reduce the texture size. The final optimized 3D models ranging from 50 MB to 90 MB (Fig. 3 and Table 1). In the following three case studies are presented: (a) the Bartoccini tomb, (b) the Inscriptions tomb and (c) the Bettini tomb. In Section 3.4 a further development of the VR application to a Virtual Tour (VT) of an archaeological areas is presented.

3.1. Bartoccini tomb

The Etruscan Bartoccini tomb (VI cent. BC) is composed of four rooms – a principal burial chamber, with beautiful frescoes, which give access to the other three rooms. The tomb is approximately 2.7 m high with an area of ca. 44 m^2. The survey delivered ca. 1.5 millions of points and the final polygonal model is composed of ca. 3 millions of faces. The texturing was done using high resolution panoramic images mapped onto the polygonal 3D model of the tomb. The final file size is ca. 520 MB (including the texture). These characteristics deny a fluent and interactive real-time access to the virtual tomb to non-expert heritage users. Contrarily the developed VR application allows to walk-through the digitized tomb, access to digital contents and easily analyze the chambers frescoes (Fig. 4a and b).

3.2. The Inscriptions tomb

The Etruscan Inscriptions tomb (IV-II cent. BC) is composed of seven rooms – a central atrium with access to six burial chambers. The hypogeum is approximately 3.4 m high with an area of

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ca 90 m^2. The tomb lacks of frescoes, however it is characterized by many inscriptions on the walls (in Etruscan and Latin language) which describe persons from different families buried there. The survey collected ca. 2.4 millions of points, delivering a final polygonal model with ca 5 mil faces. Due to the homogeneity of the material (*tufo*) and the complex geometry that characterizes the tomb (irregular rooms full of tombstones and sarcophagus creating occlusions), virtual textures were used to texture the materials, while, high resolution images were used to map the inscriptions through photogrammetric methods. The final file size is ca. 700 MB (including the texture). The textured 3D model was imported in Unity and different lights were used in order to highlight not only the three-dimensional perception but also to better recreate the real environment. The inserted hot-spots allow the user to interactively obtain historical information about the tomb and visualize the various inscriptions [52] together with their translation (Fig. 4c and d).

3.3. Bettini tomb

The Etruscan Bettini tomb (V cent. BC) is a single room structure with a gabled roof, various frescoes and a burial moat dug in the ground. The tomb is approximately 2.5 m high with an area of ca. 12 m^2. The final photo-realistic 3D model of the tomb has ca. 2 millions of polygons. The geometry of the chamber was texture-mapped through panoramic projections while the burial moat, due to its narrow dimensions, was textured by flat projections of high resolution images. The file size of the tomb is ca. 200 MB (including the texture). It faithfully represents the current status of the Etruscan burial with many ruined frescoes. For conservation and archaeological purposes, a virtual hypothetical reconstruction of the frescoes was performed using Etruscan paintings analyses [53] and iconographic studies of similar tombs and materials (Fig. 5a and b). For this purpose, orthophotos and rectified images of the current status of the tomb were produced using high resolution images (acquired by a Nikon D3X camera, 24.5 megapixel Full-Frame (36 × 24 mm) sensor with fixed lenses Nikkor 24 and 50 mm) and reality-based 3D models. The obtained flat images were used to design the hypothetical reconstruction of the frescoes and subsequently restored digital images were used to texture the geometry of the 3D model. In this way, a new 3D model of the virtual hypothetical status of the Bettini tomb was created. Both 3D models (actual and hypothetical situation) were imported in Unity in a common reference system, overlapped with the same origin and orientation and used to create a temporal VR visualization to compare the different situations (Fig. 5c–e). Thanks to the Kinect sensor, which observes the gesture of the user while he/she navigating inside the tomb, within the Oculus headset the different temporary scenes can be activated and observed.

3.4. Further application

The developed VR application can be used not only for huge and complex reality-based 3D models but also for different purposes such as Virtual Tours (VT) of archaeological sites. In order to verify the reliability of the presented methodology, a VT realized for the archaeological area in Paestum [54] was tested. The Paestum VT is composed of 20 very high-resolution panoramic images spread all over the site (ca 1 × 0.6 km). In addition, historical information related to the main monuments was collected to enrich the tour. The high resolution panoramic images as well as the historical digital information are integrated inside Unity, and through Oculus Rift an immersive visualization of the enriched images is realized (Fig. 6). The user can navigate through the different panoramic scenes and landscapes and retrieve access to the information of archaeological site without being at the site.

4. Conclusions

The paper presents the interactive and immersive visualization and access of large and complex reality-based 3D model using Virtual Reality (VR) techniques. The developed and implemented methodology rely on VR devices and natural user interfaces integrated using a game engine software. The outcomes allow to access, visualize and divulge digital archaeological sites which are normally not accessible due to hardware limitations and large file sizes. Unity plays a fundamental role (i) for the management of complex reality-based 3D models and high resolutions panoramic images and (ii) for the integration, synchronization and processing of various devices and data. Indeed Unity must communicate with different devices in order to coordinate a second display (Oculus Rift) and acquire and process the 3D data observed by the Kinect. The presented VR solution includes also an easy and intuitive user interface that allows the user, once immersed into a virtual world, to explore a 3D scene and, simultaneously, to retrieve digital media contents (like historical data). Such user interface was realized considering to whom the application is addressed (scientific community, tourists, students, etc.), in order to design and implement it with the best results, in an intuitive and user-friendly way.

The limitations of the developed VR solution are the uploading time of large 3D datasets into Unity, the actual constraint of CPU and GPU as well as the working range of the Kinect sensor. All these issue will for sure be soon solved by the continuous ICT developments. Nevertheless the presented work represents an innovative application in the Cultural Heritage field. Even huge and complex reality-based 3D models could be integrated into a unique VR application, in order to exploit the intrinsic advantages of the different digital datasets. It can be used not only for visualization, enriching unique experiences for visitors in museums, exhibitions and educational purposes but also for scientific applications of heritage sites. VR technology can offer scholars to visit digital archaeological areas, like in a real-world context. It enables a non-destructive way for archaeologists, historians, and other academics to inspect archaeological sites, providing accurate and precise details of monuments (based on the resolution of the 3D model used), without damaging, dirtying or altering heritage sites. Advanced tools allow the access to digital media contents, thus the VR application becomes a container of data. Furthermore, it is possible to travel through a temporary space as the 3D data visualized in the VR application can represent the same Cultural Heritage site at different times, turning into a reality-based 4D virtual world. Adding multiples layers allows to create different levels of information (e.g. different conservation states, various hypothetical reconstructions, etc.). As a result, the users will be able to virtually travel to locations with difficult access, distances places or different eras in order to know the past and present of the site. Additionally, people with limited mobility can virtually visit, explore and enjoy Cultural Heritage sites through reality-based VR applications. In the researcher field, scientists, archaeologists, conservator and architects could be able to use the VR application as a database with dedicated cultural information (textual information, images, metadata, etc.), aside from planning, predicting, simulating and visualizing future interventions. Scientists and researchers located in different places could visualize and investigate the same archaeological sites, at the same time, in order to facilitating collaborative research and data sharing.

The presented methodology was showcased during the 2015 EU Research Night (Fig. 6d) and it is now on show in the travelling multimedia exhibition about the Etruscan civilization.

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References

[1] G. Vosselman, H. Maas, Airborne and Terrestrial Laser Scanning, CRC, Boca Raton, 2010, ISBN 978-1904445-87-6.
[2] F. Remondino, S. El-Hakim, Image-based 3D modelling: a review, Photogramm. Rec. 21 (115) (2006) 269–291.
[3] K. Lambers, H. Eisenbeiss, M. Sauerbier, D. Kupferschmidt, T. Gaisecker, S. Sotoodeh, T. Hanusch, Combining photogrammetry and laser scanning for the recording and modelling of the Late Intermediate Period site of Pinchango Alto, Palpa, Peru, J. Archaeol. Sci. 34 (10) (2007) 1702–1712.
[4] G. Guidi, F. Remondino, M. Russo, F. Menna, A. Rizzi, S. Ercoli, A multi-resolution methodology for the 3D modeling of large and complex archaeological areas, Int. J. Archit. Comput. 7 (1) (2009) 39–55.
[5] F. Remondino, S. El-Hakim, S. Girardi, A. Rizzi, S. Benedetti, L. Gonzo, 3D Virtual Reconstruction and Visualisation of Complex Architectures – The 3D-ARCH Project, vol. 38(5/W1), International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Trento (Italy), 2009.
[6] F. Nex, F. Rinaudo, LiDAR or photogrammetry? Integration is the answer, Ital. J. Remote Sens. (2011) 107–121, http://dx.doi.org/10.5721/ItJRS20114328.
[7] P. Grussenmeyer, E. Alby, T. Landes, M. Koehl, S. Guillemin, J. Hullo, E. Smigiel, Recording approach of heritage sites based on merging point clouds from high resolution photogrammetry and terrestrial laser scanning, Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. 34 (B5) (2012) 553–558.
[8] P. Bastonero, E. Donadio, F. Chiabrando, A. Spanò, Fusion of 3D models derived from TLS and image-based techniques for CH enhanced documentation, ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci. II-5 (2014) 73–80.
[9] F. Remondino, F. Menna, A. Koutsoudis, C. Chamzas, S. El-Hakim, Design and implement a reality-based 3D digitisation and modelling project, in: Proceedings of the IEEE Conference Digital Heritage, vol. 1, 2013, pp. 137–144, http://dx.doi.org/10.1109/DigitalHeritage.2013.6743723.
[10] L. Pecchioli, M. Pucci, F. Mohamed, B. Mazzei, Browsing in the virtual museum of the Sarcophagi in the Basilica of St. Silvestro at the Catacombs of Priscilla in Rome, in: Proc. of the 18th Int. Conference on IEEE Virtual Systems and Multimedia (VSMM), 2012.
[11] Th. Kersten, 3D scanning and modelling of the Bismarck monument by terrestrial laser scanning for integration into a 3D city model of Hamburg, in: M. Ioannides, D. Fellner, A. Georgopoulos, D.G. Hadjimitsis (Eds.), Digital Heritage, 3rd International Conference, EuroMed 2010, Lemessos, Cyprus, November 8–13, Lecture Notes in Computer Science, vol. 6436, Springer Link, 2010, pp. 179–192.
[12] L. Cipriani, F. Fantini, S. Bertacchi, 3D models mapping optimization through an integrated parameterization approach: cases studies from Ravenna, Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XL-5 (2014) 173–180, http://dx.doi.org/10.5194/isprsarchives-XL-5-173-2014.
[13] B. Jiménez Fernández-Palacios, C. Stefani, J. Lombardo, L. De Luca, F. Remondino, Web visualization of complex reality-based 3D models with NUBES, in: Proceedings of the IEEE Conference Digital Heritage, Marseille, France, 28 Oct–1 Nov, vol. 1, 2013, pp. 701–704.
[14] J. Von Schwerin, H. Richards-Rissetto, G. Agugiaro, F. Remondino, G. Girardi, The MayaArch3D project: a 3D web system for querying ancient architecture and landscapes, in: Proceedings of the Int. Conference Digital Humanities, Hamburg, Germany, 16–22 July, 2012.
[15] J. Von Schwerin, H. Richards-Rissetto, F. Remondino, M.G. Spera, M. Auer, N. Billen, L. Loos, L. Stelson, M. Reindel, Airborne LiDAR acquisition, post-processing and accuracy-checking for a 3D WebGIS of Copan, Honduras, J. Archaeol. Sci. Rep. 5 (2016) 85–104, http://dx.doi.org/10.1016/j.jasrep.2015.11.005.
[16] M. Potenziani, M. Callieri, M. Dellepiane, M. Corsini, F. Ponchio, R. Scopigno, 3DHOP: 3D heritage online presenter, Comput. Graph. 52 (November) (2015) 129–141, ISSN 0097-8493.
[17] Y. Bastanlar, N. Grammalidis, X. Zabulis, E. Yilmaz, Y. Yardimci, G. Triantafyllidis, 3D reconstruction for a cultural heritage virtual tour system, ISPRS Arch. Photogramm. Remote Sens. 37 (5) (2008) 1023–1028, Beijing, China.
[18] B. Jiménez Fernández-Palacios, F. Nex, A. Rizzi, F. Remondino, ARCube – the augmented reality cube for archaeology, Archaeometry (2014), http://dx.doi.org/10.1111/arcm.12120.
[19] J.A. Barceló, Visualizing what might be. An introduction to virtual reality in archaeology visualizing archaeological data, in: Virtual Real. Archaeol. 2000. No. Goldstein 1996, 2000, pp. 9–36.
[20] Y. Boas, Overview of Virtual Reality Technologies, 2013, Mms.Ecs.Soton.Ac.Uk.
[21] G. Papagiannakis, S. Schertenleib, B. O'Kennedy, M. Arevalo-Poizat, N. Magnenat-Thalmann, A. Stoddart, D. Thalmann, Mixing virtual and real scenes in the site of the ancient Pompeii, Comput. Anim. Virtual Worlds 16 (1) (2005) 11–24, Series: Comput. Animat. & Virtual Worlds (UK).
[22] Oculus, V. R. Website. https://www.oculus.com/ (accessed 07.04.16).
[23] P.R. Desai, P.N. Desai, K.D. Ajmera, K. Mehta, A review paper on oculus rift – a virtual reality headset, IJETT Int. J. Eng. Trends Technol. 13 (July (4)) (2014) 175–179, ISSN: 2231-5381.
[24] I. Goradia, J. Doshi, L. Kurup, A review paper on oculus rift & project Morpheus, Int. J. Curr. Eng. Technol. 4 (5) (2014) 3196–3200, E-ISSN: 2277-4106, P-ISSN: 2347-5161.
[25] Samsung Gear VR. http://www.samsung.com/global/microsite/gearvr/ (accessed 07.07.16).
[26] Neo Pro. http://light-and-shadows.com/ (accessed 07.07.16).
[27] Kinect. https://www.microsoft.com/en-us/kinectforwindows/ (accessed 07.07.16).
[28] Google Cardboard. https://www.google.com/get/cardboard/ (accessed 04.09.16).
[29] OpenDive. http://www.durovis.com/opendive.html (accessed 04.09.16).
[30] F. Tschirschwitz, T. Kersten, K. Zobel, Interactive 3D visualisation of architectural models and point clouds using low-cost-systems, in: M. Ioannides, N. Magnenat-Thalmann, E. Fink, R. Zarnic, A.-Y. Yen, E. Quak (Eds.), Proceedings of the 5th International Conference EuroMed, Limassol, Cyprus, November 3–8, Lecture Notes in Computer Science (LNCS), vol. 8740, Springer International Publishing, Switzerland, 2014, pp. 268–278.
[31] N. Villaroman, D. Rowe, B. Swan, Teaching natural user interaction using OpenNI and the Microsoft Kinect sensor, in: Proceedings of Conference Information Technology Education, ACM (SIGITE'11), West Point, NY, USA, October 20–22, 2011, p. 227, http://dx.doi.org/10.1145/2047594.2047654.
[32] H. Richards-Rissetto, F. Remondino, G. Agugiaro, J. Robertsson, J. Von Schwerin, G. Girardi, Kinect and 3D GIS in archaeology, in: G. Guidi, L. Addison (Eds.), Proceedings of the 18th Int. Conference on Virtual Systems and Multimedia (VSMM), Milan, Italy, 2012, pp. 331–337, http://dx.doi.org/10.1109/VSMM.2012.6365942.
[33] Structure. http://www.structure.io/ (accessed 07.04.16).
[34] Leap Motion. https://www.leapmotion.com/ (accessed 04.09.16).
[35] D.A. Bowman, C. Wingrave, J. Campbell, Using Pinch Gloves^{TM} for both natural and abstract interaction techniques in virtual environments, in: HCI International, 2001, pp. 629–633.
[36] Control VR. http://controlvr.com/ (accessed 04.09.16).
[37] Thalmic. https://www.thalmic.com/myo/ (accessed 04.09.16).
[38] K. Pietroszek, A. Kuzminykh, J.R. Wallace, Smartcasting: a discount 3D interaction technique for public displays, in: OzCHI, Sydney, Australia, ACM, 2014, ISBN: 9781450306539.
[39] A. Sherstyuk, D. Vincent, A. Treskunov, Towards Virtual Reality games, in: Proceedings of the 8th International Conference Virtual Real. Contin. Appl. Ind. (VRCAI), 2009, p. 315, http://dx.doi.org/10.1145/1670252.1670322.
[40] H.G. Hoffman, W.J. Meyer, M. Ramirez, L. Roberts, E. Seibel, B. Atzori, S. Sharar, D.R. Patterson, Feasibility of articulated arm mounted oculus rift virtual reality goggles for adjunctive pain control during occupational therapy in pediatric burn patients, Cyber Cyberpsychol. Behav. Soc. Netw. 17 (6) (2014) 397–401, http://dx.doi.org/10.1089/cyber.2014.0058.
[41] A. Rizzo, J. Morie, J. Williams, J. Pair, J. Buckwalter, Human emotional state and its relevance for military VR training, in: Proceedings of the 11th International Conference on Human–Computer Interaction, Las Vegas, Nevada, USA, 22–27 July, 2005.
[42] E.J. Tatton III, The Future Impact of Immersive Virtual Reality Simulations on the Suburban Training Experience of Firefighters in Westchester, NY, Master of Science Degree, School of Arts and Science State University of New York Polytechnic Institute Utica, New York, 2014.
[43] A. Magnelli, Use of Oculus Rift for an immersive "time-shift" experience in the Medieval Ages, in: Proceedings of the Conference on Cultural Heritage and New Technologies, Vienna, Austria, 3–5 November, 2014.
[44] M. Forte, N. Lercari, E. Shiferaw, R. Kopper, Reshaping remote sensing and virtual reality at Çatalhöyük, in: Proceedings of the 5th International Conference on Remote Sensing in Archaeology, The Age of Sensing, Duke University Durham, North Carolina, USA, 13–15 October, 2014.
[45] S. Pescarin, A. Pagano, M. Wallergård, W. Hupperetz, C. Ray, Evaluating Virtual Museums: archeovirtual case study, CAA2012, in: Proceedings of the 40th Conference in Computer Applications and Quantitative Methods in Archaeology, Southampton, United Kingdom, 26–30 March, 2012.
[46] Dutch Rijksmuseum. The museum of the future. www.rijksmuseum.nl/en (accessed 04.09.16).
[47] ArcTron. http://www.arctron.de/en/services/multimedia/interactive_systems/ (accessed 04.09.16).
[48] ETT. http://www.ettsolutions.com/News.aspx?id=738/ (accessed 07.04.16).
[49] Universidad de Alicante, Patrimonio Virtual Website. http://www.patrimoniovirtual.com/2013/09/12/oculus-rift-sumergiendonos-en-realidad-virtual/ (accessed 04.09.16).
[50] F. Remondino, A. Rizzi, B. Jiménez Fernández-Palacios, G. Agugiaro, G. Baratti, R.D.E. Amicis, The Etruscans in 3D: from space to underground, in: Proc. 23rd Int. CIPA Symposium, Prague, Czech Republic, 2011.

[51] B. Jiménez Fernández-Palacios, A. Rizzi, F. Remondino, Etruscans in 3D – surveying and 3D modeling for a better access and understanding of heritage, Virtual Archaeol. Rev. 4 (8) (2013) 85–89, ISSN: 1989-9947.

[52] Studi etruschi. Vol. XXXI. Serie II, Istituto di studi Etruschi ed Italici. Leo S. Olschki – Book Co. Italia Srl.

[53] S. Steingraeber (Ed.), Catalogo ragionato della pittura Etrusca, Jaca Book, 1985, ISBN 88-16-60046-2.

[54] F. Fiorillo, B. Jiménez Fernández-Palacios, F. Remondino, S. Barba, 3D surveying and modelling of the archaeological area of Paestum, Italy, Virtual Archaeol. Rev. 8 (4) (2013) 55–60.

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