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# PHOTOGRAMMETRY AND AUGMENTED REALITY FOR CULTURAL HERITAGE APPLICATIONS

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*Abstract*

*Virtual modelling and 3D reconstruction are common tools used in the field of cultural heritage to recreate, analyse and visualise large objects (for example, archaeological sites and architectural buildings) and small objects such as sculptures, ceramic tiles or silver, marble and wooden artefacts. At present, it is possible to apply different technologies to achieve accurate photo-realistic 3D models. On the one hand, the precise modelling of existing 3D data is usually difficult and expensive as "reality" is complex per se; the more complex the object, the more complex the model. On the other hand, models are often achieved with the purpose of visualising the past state of monuments that nowadays are no longer fully conserved. In this sense, "augmented reality" (AR) technology can play an important role in cultural heritage. First, it permits the simultaneous viewing of both virtual and real 3D data. Second, the modelling of the entire object is no longer necessary. Third, it is possible to have full "immersion" of the viewer. This paper overviews the new technology of AR, as used in the world of cultural heritage to display past (now partially or totally lost) and present scenes together. It goes on to describe some practical experience of applying AR to the re-creation of two features, a Baroque vault and a Renaissance reredos, formerly present above the high altar of Valencia Cathedral in Spain.*

Keywords: augmented reality, cultural heritage, head-mounted display, immersion, pose estimation, 3D reconstruction, virtual modelling

## Introduction

The evolution of modern microprocessors and computer memories during the past decade has made the acquisition, recording and manipulation of virtual 3D data technically affordable, even with standard personal computers. The increasing interest that the scientific community is devoting to the field of 3D modelling of cultural heritage (CH) is due, according to Pieraccini et al. (2001), to the needs of conservation, including tasks (among others) such as the compilation of digital archives of 3D models, the acquisition of high-fidelity physical replicas of works of art, remote access to digital models of CH artefacts (described by Pieraccini et al. as "remote fruition") and the possibility of digital restoration and monitoring of CH. It is possible to find in the literature many scientific papers dealing with the 3D reconstruction of CH. For example, in Boehler et al. (2003) a digital model of the tomb of the German Emperor


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Maximilian I is achieved with both close range photogrammetry and 3D scanning techniques. In Gutierrez et al. (2004) the ancient Muslim suburb of Sinhaya (Zaragoza, Spain) is reconstructed using topographical techniques, from which accurate models and textures are obtained, and special light conditions are virtually added in order to enhance realism. In Koutsoudis et al. (2007) a photo-realistic 3D reconstruction is achieved for a part of the old city of Xanthi (Thrace, Greece) by using open-source systems based on 3D graphics.

Most computers today facilitate real-time multimedia applications that combine images, videos, 3D data and/or sound. Augmented reality (AR) is a rapidly emerging new technology that allows the visualisation of hybrid environments, real and virtual. The latter refers to all kinds of multimedia products that are used to enhance or augment the real part. This technology has been proven to have great potential in many different areas, such as education (Ben-Joseph et al., 2001; Cobb et al., 2002; Kaufmann and Schmalstieg, 2003; Gillet et al., 2004), entertainment (Romero et al., 2004; Roussou, 2004; Zhou et al., 2004; Cheok et al., 2006; Rashid et al., 2006; Souza e Silva and Delacruz, 2006), medicine (Nikou et al., 2000; Weidenbach et al., 2000; Rosenthal et al., 2002; Fischer et al., 2007) or the arts (Galantay et al., 2004; Giner Martínez and Portalés Ricart, 2005; Portalés, 2007). However, the number of studies that specifically tackle the field of CH is limited. For example, in Aguiló et al. (2001) and Gleue and Dähne (2001) a prototype system of augmented reality for archaeological site visits is proposed. It is an outdoor application with six degrees of freedom visualised on a tablet PC. In Gleue and Dähne (2001) and Vlahakis et al. (2001) the ARCHEOGUIDE project makes use of AR for reconstructions of ancient ruins, based on the user's position and orientation in the cultural site obtained by means of a differential global positioning system (DGPS) and a magnetic compass, together with real-time image rendering.

This paper presents a low-cost AR application, based on open-source software, created to display the Baroque vault which stood above the high altar of Valencia Cathedral from the 17th century until it was dismantled in 2006, and also the silver relief interior of the Renaissance reredos (altarpiece), which was present from around 1500 until the early 19th century. The aim is to recreate the former scenarios in real time inside the cathedral, as they were when those works of art existed *in situ*. This paper will focus on two different aspects: on the one hand, the system and user interaction with it; and on the other hand, understanding of the cultural site and the history which led to the present situation inside the cathedral. Furthermore, it also highlights the benefits that AR technology can bring to the field of CH. The paper is organised as follows: first, a review of AR technology is given, focusing on its benefits and certain issues with regard to the image registration process in real time. Then follows an explanation of the works related to the development of this AR tool applied to the surroundings of the high altar of Valencia Cathedral. Results obtained on three different case studies are presented and discussed, where in the first case study, only the vault is augmented; in the second, only the reredos is augmented; and in the third, both the vault and the reredos are augmented. Finally a usability test is presented and conclusions are derived.

## Augmented Reality Technology

### *Definition and Benefits*

The terms 3D models and virtual reality (VR) are well known. In a virtual environment senses, such as sight, hearing and touch, are controlled by a computer, while actions influence the stimuli produced. In contrast to traditional VR systems, in AR the real environment is not completely suppressed, playing instead an important role (Bimber and Raskar, 2005). Its basic concept is to place computer-generated multimedia into the user's perception (usually field of view), registered within the environment. AR is not only applied to the visual sense; all other senses can be augmented as well.

Several characteristics of AR can produce benefits in the world of CH, mainly as regards acquisition, management and dissemination. First, it helps to reduce time and final costs related to acquisition, modelling and management due to the non-modelling of the present scenario. Second, it can improve the understanding of CH, as it has the power to generate hybrid environments (real and virtual), mixing together past (non-existing part, virtually modelled) and present (real part, not modelled) scenarios. Third, AR improves user immersion over VR systems, as the user can move around, see the objects in their present size and explore them in a more natural way, thus allowing applications in real time, on site.

### *Registration in Real Time*

One of the main challenges of AR is to keep the computer-generated objects accurately registered to the real world so that they appear to the user as fixed in the environment, for instance, when watched through the head-mounted display (HMD). Accurate tracking in real time still requires further research, as accuracy is crucial and this will depend essentially on the nature and resolution of the sensors (for example, GPS, inertial navigation system (INS) or vision-based) or the methodologies applied. Most of the current research in AR is focused on developing minimum-latency tracking, high accuracy and comfortable lightweight portable devices.

Different methodologies may be used to achieve registration in real time. For example, the combination of a DGPS receiver and an INS sensor is quite common. These surveying systems are commonly applied in AR systems for outdoor applications and are usually integrated in wearable mobile systems (Azuma et al., 1999; Demiris et al., 2005). Demiris et al. (2006) give a comprehensive review of mobile AR systems used in the field of CH.

Vision-based systems are extensively used for registration purposes in both photogrammetry (Kraus, 1997; Lerma García, 2002) and computer vision (Trucco and Verri, 1998). They are also used to build up AR applications in order to determine camera pose (exterior orientation) and measure features from single or multiple images. These systems are applied to both outdoor and indoor applications, although they are easier to implement indoors due to simpler lighting conditions.

It is possible to make use of either commercial or open-source software to build up AR applications, for example, ARToolKit (HITLab, 2007), MXRToolKit (MXR Lab, 2004), ARTag (ARTag, 2007) or BazAR (CVLAB, 2007). The first three are marker-based, thus a physical target with special characteristics should be placed in the scene to register camera pose. The latter is image-based and does not require any marker, simply a source image to establish correspondences. All these systems require a calibrated camera with known interior orientation parameters. The AR application was implemented following the vision-based open-source BazAR libraries, firstly because of the flexibility they offer in building up the AR environment and secondly because of the possibility of camera pose estimation in real time.

### *User Experience*

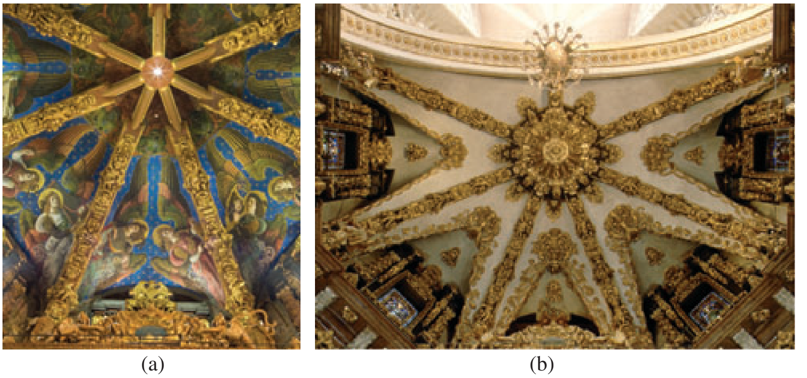
One of the major goals is to provide users with a better understanding of cultural sites through AR applications. A critical point affecting users is the compatibility between the real and virtual scenarios (Barfield and Furness, 1995; Wang and Dunston, 2006). This means that the environment generated should be plausible for the users in terms of perception and cognition. To achieve this, several aspects can be considered, including correct perspective between the virtual and real worlds, correct spatial alignment and rapid response. Furthermore, the type and characteristics of the display are also critical, along with the ergonomics of the equipment. A correct balance among all these factors will provide users with a deeper immersion, transforming the synthetic world into a believable new environment. In order to take into account the user's experience achieved in an AR system, usability tests can be carried out.

## AR for the High Altar of Valencia Cathedral

In the AR application for Valencia Cathedral (hereafter referred to as AR-Cathedral), the augmentation is applied to the interior of an existing central Gothic vault with Renaissance frescos. The aim is to visualise a Baroque vault which existed between 1682 and 2006 and which was digitised with a 3D terrestrial laser scanner before it was dismantled (Lerma et al., 2006; Biosca Taronger et al., 2007). The existing reredos which surmounts the high altar is also augmented by means of a photograph of a wooden replica of its former Renaissance silver relief interior panel. In the following sections, a brief history of the augmented objects is presented and the components of the AR-Cathedral system are explained.

### *Brief History and Significance of Both the Vault and the Reredos*

Valencia Cathedral dates back to 1262, and represents a variety of styles including Romanesque, Gothic and Baroque. The cathedral is mainly of early Gothic style, although the high altar is in the Baroque style despite its central Renaissance reredos. After some restoration works around the high altar in 2004, it was found that the Baroque vault had been covering up another more ancient Gothic vault that had remained hidden for more than three centuries (Fig. 1(a) and (b)). The most important part of this discovery was that the whole Gothic vault provided the physical support for unique early Renaissance frescos of musical angels (Fig. 2) painted by two Italian master painters, Franco Pagano and Paolo de San Leocadio (Pérez García, 2006). After discussion of this remarkable find, the Baroque vault was finally dismantled in order to expose the Gothic vault supporting the frescos. Prior to dismantling, a



(a) (b)

Fig. 1. (a) Detail of present-day Gothic vault above the high altar,
(b) Baroque vault *in situ* before dismantlement.

FIG. 2. Details of two previously hidden angels playing musical instruments (Renaissance frescos on the Gothic vault).

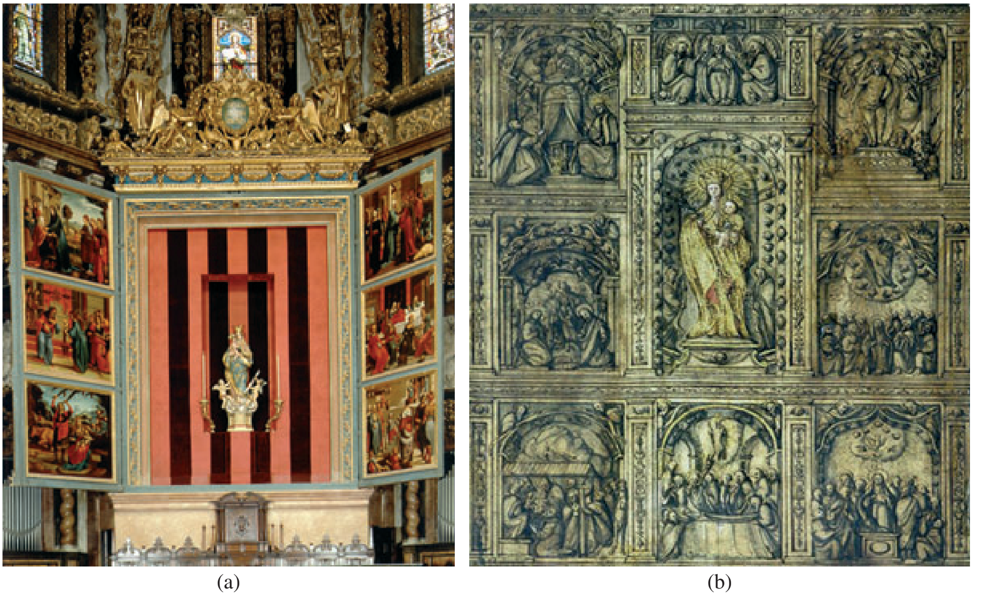
complete 3D reconstruction of the Renaissance frescos (Lerma et al., 2005) as well as a 3D digitisation of the Baroque vault (Biosca Taronger et al., 2007) were carried out in order to accurately document their shape, character and morphology.

Regarding the vanished silver reredos, some information can be found in Las Provincias (2006). It was constructed between 1489 and 1506 by Piero da Ponce, Augustine Nicos and the Valencian silversmiths Francisco Cetina and Bernat J. Cetina. The reredos represented the Seven Joys of the Virgin, with a central image representing the Assumption, and a Coronation of the Virgin at the top. The ensemble was completed with its monumental doors that were opened only during important festivals to spectacular effect, decorated on both sides with Marian themes. In the early 19th century this silver reredos was melted down in Majorca during the War of Independence, to convert into currency and pay foreign troops who cooperated with Spain in the fight against Napoleon. Nowadays, the only remnant of this work of art is an 18th-century wooden tablet that is preserved in the archives of the cathedral. An image of this replica of the original is used here for the augmentation; the original doors are fully conserved and remain *in situ* (Fig. 3).

### *3D Digitisation of the Vault*

A range of techniques from direct manual measurement to instrumental surveying, laser scanning and/or photogrammetry can be used to support the 3D digitisation of existing monuments (Pavlidis et al., 2007). In order to achieve highly accurate metric documentation of the Baroque vault, a Faro LS 880 high-resolution terrestrial laser scanner was used to measure, plot and recreate a full 3D model. The size of the whole vault was approximately 12 m × 9 m wide × 7 m high. A total of 18 scanner stations were set up at two different levels, acquiring more than 172 million points. The fixed resolution was 2 mm at 7 m range. However, for modelling purposes after registration, the amount of data was downsampled to 1 cm spacing. The overall accuracy of the triangulation was better than 5 mm. Furthermore, a Canon EOS D60 digital reflex camera was used to record texture information and the radiometric data was also used for draping purposes. The complete procedure used to build up the 3D model can be found in Lerma et al. (2006). A snapshot of the resulting 3D model is shown in Fig. 4. For AR-Cathedral, the 3D model was further simplified to allow real-time interaction (see next section).



(a) (b)

FIG. 3. (a) Current interior of the reredos at the high altar (doors open), (b) image of a wooden replica of the lost silver relief.

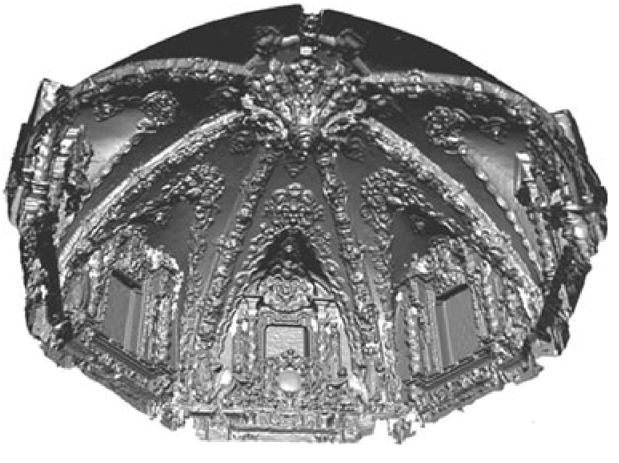


FIG. 4. 3D model of the Baroque vault captured by means of a Faro LS 880 terrestrial laser scanner.

### *AR Configuration*

In this application the user wears all the devices needed to generate and display the augmented environment in such a way that no other elements (such as markers, sensors or display devices) are left in the surroundings. Following this procedure, the fabric of the

FIG. 5. Laptop computer, HMD and web camera used in the AR application.

cathedral itself remains unaltered. Another main feature is that the user is able to move freely within a 2 m × 2 m area situated under the vault. The whole system consists of (Fig. 5):

(a) A standard laptop computer inside a backpack or carry bag.
(b) A display system. Specifically, an i-glasses SVGA video-based HMD was used, with a resolution of 800 × 600, 26° diagonal field of view and modifiable brightness; this HMD has integrated headphones, although they are not used in AR-Cathedral.
(c) A registration device. For example, a CREATIVE Live! Cam Voice web camera was placed on the top of the HMD, with 640 × 480 resolution, USB 2.0 connection and 85° field of view.
(d) Batteries for the HMD (optional).

To achieve camera pose estimation and augmentation of the real scene in real time, the BazAR libraries were used. This approach was preferred to other open-source video-based libraries (such as ARToolKit or MXRToolKit) because the latter are based on the use of markers within the scene. Instead, the BazAR process is based on feature point detection and matching, where homography between a target image and the input image (that acquired within the camera in real time) is estimated from correspondences by RANSAC (Pilet et al., 2006). Thus, no additional targets needed to be placed onto the objects to be augmented, and the surroundings remained unaltered.

In AR-Cathedral, the augmented data were both the recently dismantled Baroque vault and the lost silver reredos (Figs. 1(b), 3(a), 4). In order to render the 3D model of the vault, the model acquired with the laser scanner was simplified into a hemispherical shape. This step was necessary because of the complex geometry of the original model and the need to process all the data in real time. Therefore, the fully 3D laser model was initially generated for documentation purposes before starting any restoration activities (Lerma et al., 2006), and eventually simplified for AR-Cathedral to fit into an ellipsoidal shape. After simplification, texture data was added from a digital image. To augment the reredos a spatial plane was mapped with a photographic image of the surviving wooden replica, as the silver original was destroyed before the invention of photography. Both 3D models are introduced into the

OpenGL programming environment; textures are in Targa format because this enables alpha values.

## Validating the Application through Case Studies

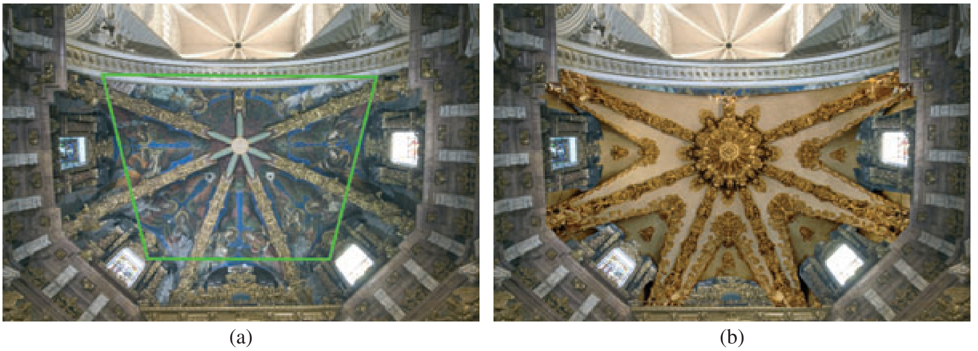
Three case studies were fulfilled within the AR-Cathedral, the first augmenting the vault, the second augmenting the reredos, and the third augmenting both the vault and the reredos. The most satisfactory case study was selected to perform a usability test. In the following paragraphs, all the results are discussed.

### *First Case Study: Vault Re-creation*

In the first round of activity, the vault was augmented. For this purpose, the vault itself was captured as a target image, and the concave vault surface was approximated to a planar feature (Fig. 6). Theoretically, this approximation is only valid when the viewing angle is strictly vertical. Therefore, the target image used to match the Baroque and Renaissance scenarios was captured while keeping the optical axis of the digital camera vertical.

The application only worked correctly inside a restricted area of $2\ \mathrm{m} \times 2\ \mathrm{m}$, just below the centre of the vault; this is the area that geometrically matches the original projection centre of the Baroque image. Nevertheless, it has to be remarked that, although the freely available version of BazAR does not allow right registration on deformable surfaces, research has been carried out by various authors to overcome this problem (Salzmann et al., 2006). In fact, BazAR's full version supports matching on non-planar targets.

An additional problem found when targeting the vault is due to lighting conditions, and in particular the daylight coming through the stained glass windows (Fig. 1). Therefore, the best conditions on site are at night, with artificial light. Although BazAR provides an automatic photometric calibration (Pilet et al., 2006) and thus it is possible to both estimate and minimise awkward lighting, conditions change greatly during the day, being especially critical at midday. This fact can be appreciated in Fig. 1: the left image was taken at night with controlled artificial light, whereas the right image was taken in the morning. The former shows even illumination while the latter presents some high intensity bright spots near the windows. Because of these problems, it was decided to study multiple lighting conditions depending on the time of day and the season. However, the solution is still unsatisfactory on account of both the lack of



(a) (b)

Fig. 6. Case study 1. (a) Vault (before final restoration) with target image marked with a green line, (b) vault augmentation over a planar image approximation.

planarity of the target and the illumination problem during daylight hours. This latter problem is aggravated by the automatic settings used for the web camera.

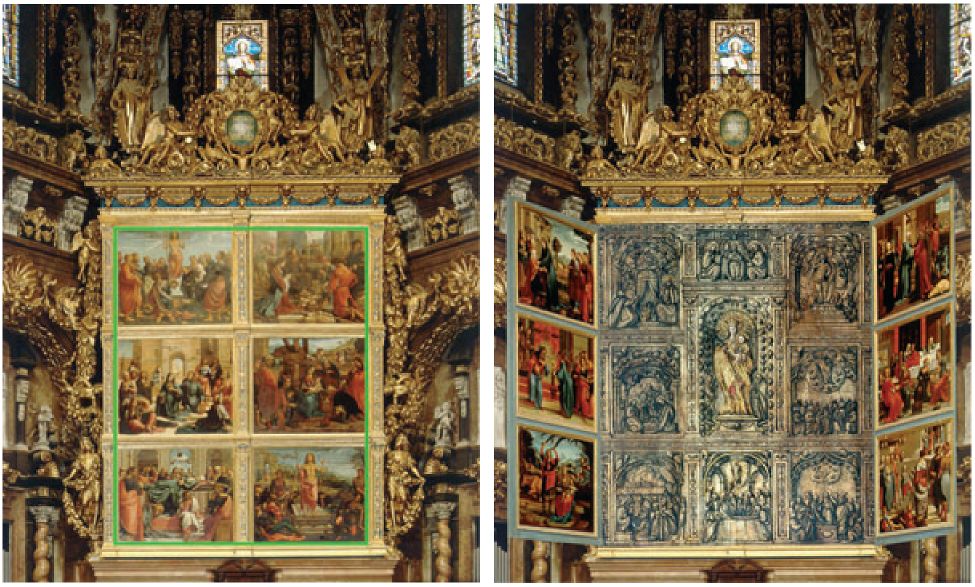
*Second Case Study: Reredos Re-creation*

In this case study, the interior of the reredos was re-created. The paintings on the outside of the closed doors of the reredos were taken as the target image, which fits onto a plane surface (Fig. 7). Therefore, the augmented data appears only when the doors of the reredos are closed, which is normally the case. The augmented data can then show both the ancient silver reredos and the paintings on the insides of the doors when they are opened. The user can see how the doors are virtually opened and the ancient silver reredos appears in the interior.

In this case study, the application works well over a larger area in front of the altar because, on the one hand, the target feature fits onto a planar surface and, on the other, bright light coming through the top of the stained glass windows does not interfere with the real-time registration process. Compared to the first case study, this one is more stable, as users can move around the altar area and it works properly both by day and by night.

*Third Case Study: Vault and Reredos Re-creation*

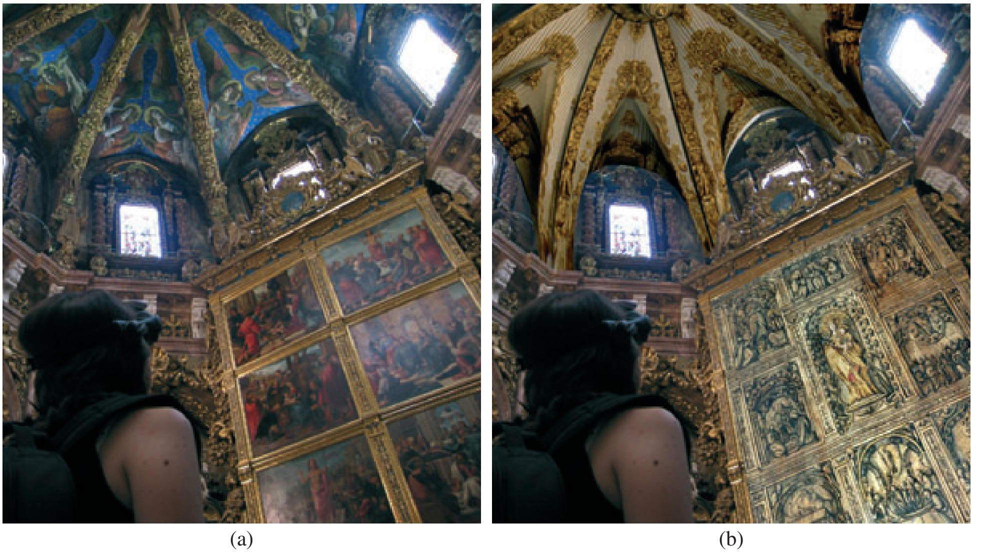
Finally, both the vault and the reredos were augmented (Fig. 8). According to the results obtained in the previous case studies, it was decided to keep the reredos as the target image, thanks to its planar shape and location and its low dependency on daylight conditions. In order to see both the vault and the reredos re-creations together, the user should be further away. Nevertheless, the use of a wide-angle camera makes this distance shorter, thus users still move around the altar area. Because the area of the target image (the reredos) occupies only about a



(a) (b)

FIG. 7. Case study 2. (a) Present-day reredos with doors closed. The target image is marked with a green line. (b) Reredos augmentation representing both the interior silver relief and the opened doors.



(a) (b)

FIG. 8. Case study 3. User with laptop, HMD and web camera. (a) Current image of both reredos and vault, (b) augmented vault over an ellipsoidal approximation and augmented reredos.

quarter of the field of view of the web camera, the real-time registration process was less accurate than the second case study and the application was also somewhat unstable. A solution for this was to take a larger area, still centred on the reredos, as the target image, while accepting the consequences of it not fitting perfectly to a planar surface. The results proved satisfactory, as the system could achieve correspondences between target and input images with a reliability of 65% as the user moved around the high altar.

## VALIDATING THE APPLICATION THROUGH USABILITY TESTS

To validate this application, a test was performed *in situ*, targeting the reredos re-creation (second case study). Users wear the HMD with the web camera as well as the backpack containing the laptop computer. In Fig. 9 some users are seen in front of the reredos carrying these devices. Interaction is produced with the simple movements of the user within the 2 m × 2 m centred area. Thus, no additional remote control is necessary and interaction is fully intuitive. A total of 48 people (24 male and 24 female) with ages ranging from 15 to 60 years tested the application. After the experience, all the users filled in a short questionnaire. They were asked to score between 1 (bad) and 10 (excellent) a total of seven factors ranging from interaction to ergonomics and compatibility. These factors are listed and, in some cases, briefly explained in the following:

(a) Interaction in real time. The faster the response of the system the more comfortably users can navigate, leading to a more natural interaction.
(b) Comfort of the wearable PC. Extra weight of the wearable PC can reduce user mobility, leading to discomfort.
(c) Comfort of the HMD. Users should consider the influence of some drawbacks related to this display such as lack of resolution, limited field of view and discomfort (Bimber and Raskar, 2005).

(a) (b)

FIG. 9. Users interacting with AR-Cathedral: (a) visitors preparing to use the system, (b) user and other visitors in front of the reredos.

(d) Design of the virtual elements and photo-realistic textures of virtual objects.
(e) Integration of the virtual elements into the real scenario.
(f) Compatibility issues.
(g) General understanding of the augmented environment.

In Fig. 10 the mean scores are shown together with their respective standard deviations. As can be seen all the scores are above 6·0 and, in general, women gave lower scores for issues related to comfort of wearable devices (questions (b) and (c)), which were also rated low by men. In fact, some users experienced a degree of insecurity when walking, especially due to the limited field of view of the HMD. The questions that achieved better scores across both groups of men and women were: compatibility, question (f), with 8·9 points (standard deviation 1·0) for men and 9·2 points (standard deviation 1·2) for women; and general understanding of the augmented environment, question (g), with 9·1 points (standard deviation 1·0) for men and 9·3

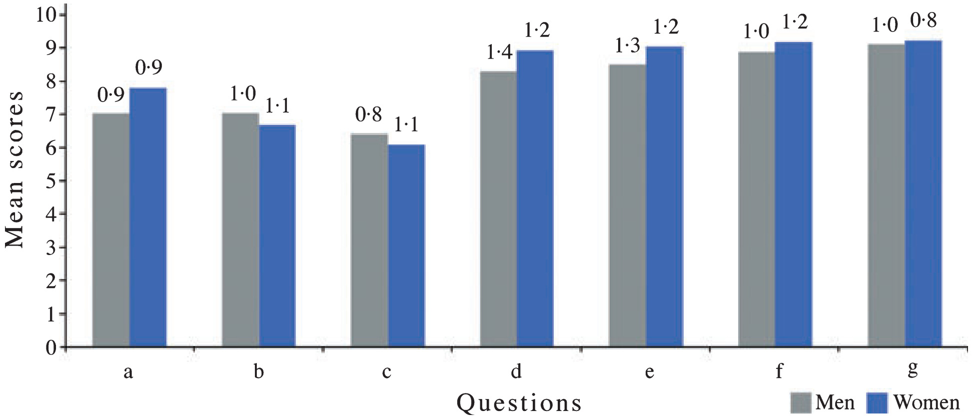



FIG. 10. Means and standard deviations (top) of users' questionnaire scores after testing the system.

points (standard deviation 0·8) for women. On the other hand, question (a) corresponding to interaction in real time was rated satisfactorily by both groups, with 7·1 points (standard deviation 0·9) given by men and 7·8 points (standard deviation 0·8) given by women. It is believed that, if case study 1 or 3 had been selected, this score would have been lower because of the drawbacks encountered. Finally, questions (d) and (e)—referring to the design of the virtual element and its integration into the real scenario—were quite highly rated with 8·3 points (standard deviation 1·4) and 8·5 points (standard deviation 1·3) given by men; and 8·9 points (standard deviation 1·2) and 9·1 points (standard deviation 1·2) given by women. It has to be pointed out that these last two questions obtained the highest standard deviations in the men's group.

Younger people (20 years old or less) felt less insecurity in testing the AR application—although the scores did not reflect significant differences in numbers—and were more willing to interact. On the contrary, older people (50 or over) were more concerned about the comfort of the HMD and laptop. People around 25 to 45 years old showed more interest in the technology, and asked several questions about the development of the application and issues related to the generation of the augmented scene. In general, most people were engaged with the application, interacting for between 3 and 5 min. Users were also asked to write a short description about their own experience. In general, they were fascinated by the technology, enjoyed the experience and highlighted the museum capabilities of the application. Some of them made some suggestions that may be considered in the future. One interesting suggestion would be to increase the number of augmented elements and complement them with the addition of sound that explains what the user can see at any given time.

## Concluding Remarks

This paper reports a successful experiment that targets real-life scenarios rather than artificial scenarios based on virtual reality (as is common for CH 3D modelling). Several AR approaches were explored for the on-site visual display of former states of decoration around the high altar of Valencia Cathedral. Archived graphic information was digitally displayed to a sample of visitors by means of AR technology. The system required the use of open-source computer vision libraries to implement the tools, as well as portable electronic devices such as HMD, laptop computer and web camera. This AR system allows users to examine, and undertake detailed research about, the past and present heritage, or simply to view both existing and lost 3D features together *in situ*. This characteristic is unlikely to be achievable in real time by other means. Moreover, these kinds of applications increase both the level of immersion and of satisfaction for the user/visitor. Thus, by bringing together features from the past into the present-day scene in real time, AR has the potential to play an important role in the understanding of historical objects, settlements and sites and it should also help in the dissemination of this history to a wider audience. Last but not least, the AR system is very easy to use, as it is based on simple physical navigation for the interaction and so can be used by all kinds of people, including those with little or no previous computer knowledge: the entire virtual world is brought to the user to enhance his or her real world.

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## *Résumé*

*La modélisation virtuelle et la reconstruction 3D sont des outils couramment utilisés dans le domaine du patrimoine culturel pour recréer, analyser et visualiser de grands objets (par exemple des sites archéologiques et des édifices architecturaux),* *et des objets plus petits comme des sculptures, des carreaux de céramique et de l'artisanat en argent, en marbre ou en bois. A présent, il est possible d'appliquer différentes technologies pour réaliser des modèles 3D précis et visuellement réalistes. D'un côté, la modélisation précise d'objets 3D existants est généralement difficile et coûteuse car la «réalité» est complexe en elle-même; plus l'objet est complexe, plus le modèle est complexe. D'un autre côté, les modèles sont souvent réalisés afin de visualiser l'état passé de monuments qui ne sont plus entièrement conservés. C'est pourquoi la technologie de la «réalité augmentée» (RA) peut jouer un rôle important pour le patrimoine culturel. Tout d'abord, elle permet la visualisation simultanée des données virtuelles et réelles. Ensuite, il n'est plus nécessaire de modéliser l'objet entier. Enfin, elle permet une totale «immersion» de l'observateur. Cet article fait le point sur la nouvelle technologie de la RA et sur son usage dans le monde du patrimoine culturel pour la visualisation simultanée de scènes passées (partiellement ou entièrement disparues) et présentes. Par ailleurs, il montre et commente des expériences ayant utilisé la RA pour la restauration de deux objets qui ont jadis fait partie de l'autel principal de la cathédrale de Valence (Espagne), une voûte baroque et un retable renaissance.*

*Zusammenfassung*

*Virtuelle Modellierung und 3D Rekonstruktion werden sehr oft als Werkzeuge für die Denkmalspflege eingesetzt, um Objekte nachzubilden, sie zu analysieren oder zu visualisieren. Die Objekte können groß sein, wie archäologische Stätten oder architektonische wertvolle Gebäude, oder aber auch klein wie Skulpturen, oder Artefakte aus Silber, Marmor oder Holz. Gegenwärtig gibt es verschiedene Technologien um genaue, fotorealistische 3D Modelle solcher Objekte zu erhalten. Einerseits ist die genaue Modellierung existierender 3D Daten üblicherweise schwierig und teuer, da die "Realität" per se komplex ist, und je komplexer das Objekt ist, um so komplexer wird das Modell. Andererseits werden Modelle oft erfasst, um einen früheren Zustand von Denkmälern zu visualisieren, die heutzutage nicht mehr voll erhalten sind. In diesem Sinne kann "Augmented Reality" (AR) eine wichtige Rolle in der Denkmalspflege spielen. Erstens erlaubt es die simultane Visualisierung von virtuellen und realen 3D Daten. Zweitens ist hierzu eine Modellierung des kompletten Objektes nicht mehr erforderlich. Drittens ist eine volle Integration des Betrachters möglich. In diesem Beitrag wird ein Überblick über die neue Technologie AR in der Welt der Denkmalspflege gegeben, um frühere, jetzt teilweise oder vollständig verschwundene Ansichten und aktuelle Ansichten gemeinsam zu visualisieren. Am Beispiel der Anwendung von AR zur Restaurierung eines barocken Gewölbes und eines Altarbildes aus der Renaissance, die früher Bestandteile des Hauptaltars der Kathedrale von Valencia waren, werden Erfahrungen reflektiert und diskutiert.*

*Resumen*

*El modelado virtual y la reconstrucción 3D son herramientas comunes utilizadas en el campo del patrimonio cultural para recrear, analizar y visualizar objetos de pequeña escala (por ejemplo, sitios arqueológicos y edificios arquitectónicos) y de gran escala, como esculturas, baldosas de cerámica, o piezas de plata, mármol o madera. Actualmente, es posible aplicar diferentes* *tecnologías para adquirir modelos 3D fotorrealísticos precisos. Por una parte, el modelado preciso de datos existentes 3D es normalmente costoso y caro, ya que la "realidad" es compleja per se; a mayor complejidad del objeto, mayor complejidad del modelo. Por otra parte los modelos normalmente se adquieren con el objeto de visualizar un estado pasado de los monumentos que actualmente no se siguen conservando. En este sentido, la tecnología de realidad aumentada (RA) puede tener un rol importante al patrimonio cultural. En primer lugar, permite la visualización simultánea de ambos datos virtuales y reales. En segundo lugar, el modelado completo del objeto ya no es necesario. En tercer lugar, es posible experimentar una completa inmersión. Este artículo revisa la nueva tecnología de RA dentro del mundo del patrimonio cultural para visualizar de forma conjunta el pasado (parcialmente o totalmente inexistente) y el presente. Más aún, refleja y discute algunas experiencias después de aplicar la RA para recuperar dos elementos antiguamente presentes en el altar principal de la Catedral de Valencia, una bóveda barroca y un retablo renacentista.*

 