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Image-based Models Using Crowdsourcing Strategies

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Abstract

This paper aims to highlight the effectiveness of the collaboration between the modelling techniques that exploit the stereoscopic images of objects and the ability of the present-day technologies to generate images, both found in the web and gathered by other crowdsourcing techniques. Since nowadays the generation of models from images is a major low-cost resource, the whole strategy is aimed at obtaining benefits in the context of the documentation of Cultural Heritage (CH).

Assuming that the documentation of CH is the basis of the protection and the conservation policies, the chances of finding images and using them to create 3D models is particularly effective when the assets in question are at risk in danger zones (wars or areas subject to natural disasters) or in areas that, for various reasons, are difficult to access.

To demonstrate the advantage of using low-cost methods for the generation of 3D models of documentation with strategies that fall within the sphere of crowdsourcing, the case of the Vank cathedral modelling is presented. The Vank Cathedral in Isfahan in Iran is a building of the Safavid epoch (cent. XVII–XVIII) completely frescoed in the internal surfaces, where the architecture and especially the architectural decoration reach their peak.

The experimental section of the paper also explores some aspects of usability of the digital output from the image-based modelling methods. The availability of orthophotos allows and facilitates the iconographic reading of the frescoes, adding to the radiometric data, there is the metric potentiality of reading the proportions and the compositions of the organisation of the frescoes. Furthermore, simplified and suitably schematised models can be even printed and can be used in a didactic environment, such as the knowledge dissemination intended by the museums and other cultural institutions.

Keywords: Crowdsourcing, Cultural Heritage, SFM, point clouds, orthophotos, 3D printing.

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Introduction

The conservation and the valorisation of CH require an extensive documentation, both in properly historic-artistic terms, as well as regarding the physical characteristics of position, shape, colour, and geometry. In recent years, the documentation produced with digital tools of 3D survey has increased. A large number of assets around the world are physically maintained, exploiting new methods and techniques developed for 3D data recording.

The three-dimensional surveys may be accomplished through different tools and techniques with their own characteristics, problems and specificities. The two most common techniques for 3D data acquisition are the Terrestrial Laser Scanner (TLS, active sensor) and digital photogrammetry (passive sensor), which is more frequently adopted using dense matching techniques. (Chiabrando and Spanò 2013, 67–72; Barsanti et al. 2014)

Choosing the best techniques depends on many factors, including the type of object or scene to be detected, the material, the required accuracy, the project budget and the time constraints. Identifying the best way of working is the first and the most fundamental step to achieve the intended result. (Kersten and Lindstaedt 2012, 399–420)

As is known, TLS supports many different methods of acquisition data, which are rapid and automatic, but the major problems are that the costs are high and that there is a requirement for professional skills. On the other hand, advances in the fields of Photogrammetry and Computer Vision have led to significant enhancements, such as the Structure from Motion algorithm (SfM), which creates a high level of automation 3D point models of objects using overlapping images.

Regardless of the problems of scale and accuracy, which are to be dealt with under the section called image based models and crowdsourced images, in general, it is possible to assert that from these dense point models, continuous triangular surfaces, high-resolution orthoprojections of surfaces and digital surface models (DEMs) can be derived, which denotes all the 2D and 3D representations that are so useful in CH documentation projects.

This ease of building models of reality, even by non-experts, even if there is no requirement of a high precision, has triggered the connection of this interest with the crowdsourcing strategies, which raise the possibility of finding and having at disposal wide set of images related to assets.

Substantially, the meeting between crowdsourcing and models generation is particularly fruitful in the field of CH, since people are interested to be involved in processes of promotion and dissemination of the CH values. In parallel, there is an increasing awareness for contributing to the generation of digital models with the immense wealth of images available on the web or that can be collected by internet.

Crowdsourcing and Potentiality in Digital CH Domain

Despite the word “crowdsourcing” being a new coinage, it is a relatively old concept. An earliest projection of the word was first discovered in 1857 in the Oxford English Dictionary (OED). This provides evidence for the history and the utilisation of the word. The first appearance of the term crowdsourcing was in 2006 (Howe 2006). According to Howe, “crowdsourcing” represents the act of a company or an institution taking a function once performed by employees and outsourcing it to and undefined (and generally large) network of people in the form of an open call”. (Kaufmann 2014, 415)

In our time, crowdsourcing describes the act of involving many people in small pieces of a project, usually online. In educational and non-profit outreach programmes, crowdsourcing is developing in the forms of participating in an online course, collecting photos for a citizen-science project, uploading old photos for a community history project or participating in online discussions. In fact, crowdsourcing can enhance efficiency while minimising work and research costs, and by utilising the internet to request input from a dynamic and an enthusiastic group of clients can diminish the measure of time spent.

Many cultural heritage organisations, such as galleries, libraries, archives and museums (GLAMs) are utilising the digitisation of information in order to secure the long-term preservation of valuable archived material.

Some studies are deepening the relations among crowdsourcing and core activities of heritage organisations with the aim to clarify opportunities and challenges. For instance, digitisation is not only a means to ensure a long-term preservation of the information concerning fragile carriers, but also a precondition for creating new access routes to collections. It is very interesting to observe how new trends aim to classify the different types of crowdsourcing in the GLAM domain in order to point out the phases in which crowdsourcing can have a key role in the so-called Digital Content Life Cycle, and lastly identify the mutual benefits for all stakeholders. (Oomen and Aroyo 2011)

The current account suggests an enormous potential for GLAMs, which makes crowdsourcing an essential part of their development process. These concepts can help collections to be used in interesting and creative ways that will promote them to new audiences, ensuring that they remain a source of inspiration and research for years to come. These projects also allow users to discover new ideas and follow their interests down routes that they may otherwise have never discovered. (Ridge 2013, 46)

Image-based Models and Crowdsourced Images

Scientists are aware that over the past two decades, laser scanning and digital photogrammetry have emerged as important additions in providing relevant potential for promoting a revolution in the documentation and the recording of archaeological evidences or other CH items and in its subsequent dissemination. (Campana 2014, 7)

The recent use of Unmanned Aerial Vehicle (UAV) photogrammetry has enlarged considerably the ability to deliver at different scales of application accurate, metric, and detailed 3D models while ensuring the estimate of the accuracy and the reliability of the unknown parameters from the measured image correspondences. (Colomina and Molina 2014, 79–97)

The high performance of the SFM systems in terms of accuracy of obtained models still depends on topographic systems, since the use of control points calculated by topographical methods enhance the quality of results. Nevertheless, the ability to search the highest sets of tie-point and to generate very complex point clouds makes this method increasingly independent of topographic systems. (Remondino 2011, 1104–1138)

Starting from this premise, and since CH of different types in the world is at major risk of natural and human hazards, some enhanced studies are deepening the chance to derive digital documentation for preservation of these memories with the use of images available in the web.

These studies assume that the recent access of mobile devices has led to the exponential increase of image and video resources that are freely available in internet repositories and social networks.

An adopted strategy is to exploit the efficient feature-based method for correlation algorithms (SIFT) in order to search corresponding points in different images. Since the search must be performed on millions of photos on the web, some authors propose a methodology (incremental spectral clustering methods) that optimises research and decreases outliers. (Ioannides et al. 2013)

Crowdsourced imagery, together with the SfM algorithm on which 3D reconstruction platform are based, are effectively used in the scenario of the already lost assets; in these cases, the geometric accuracy of the 3D models is totally unknown, but they are certainly an important digital resource. (Stathopoulou et al. 2015, 295–300; Kyriakaki et al. 2014, 431–52)

There are even studies aimed at optimising the 3D reconstruction derived from video resources (Alsadik 2016), and certainly the whole research field is rapidly evolving.

In consequence of these new possibilities, cultural institutions, in particular museums, have engaged with crowdsourcing and citizen science projects; in this way, crowdsourcing techniques play an important role in digitising and help in making a more open, connected and smart cultural heritage with more involved users and providers. Some projects aimed to reconstruct destroyed monuments of high recall: Project Mosul (created by M. Vincent and C. Coughenour in 2015, https://projectmosul.org) aims to involve the general public for providing crowdsourced images to virtually recreate 3D models of the heritage assets. Other solutions are targeted at a more common heritage and close to the local communities: the MicroPasts community provides an entirely free platform and an open source for online participants, which support online crowdsourcing and crowdfunding projects about the historical treasures (http://micropasts.org).

Very recently, examples of scientific works that combine image resources found on the web and the professional imagery for the 3D reconstruction workflow comparison have been made available. The study applied on Palmyra is meant to demonstrate the high potential in terms of detail and accuracy of the models obtained from these strategies as well as to reconstruct models of the destroyed buildings to support the possible reconstruction projects. (Wahbeh et al. 2016)

To put some order among the many and varied experiences in a field of application fairly new and emerging as one that combines the crowdsourced resources and the 3D models generation, it is perhaps useful to make an attempt at a classification that clarifies the types of image retrieval:

- retrieval of images on the Web, using search engines that use image-matching algorithms or systems that retrieve the position of the shots from location-based systems. An example of search engine type of retrieval already available on the web is the TinEye system; an example of systems retrieving position of images is a study titled “Geo-localization of Crowdsourced Images for Collaborative 3D Modelling”, by S. Verstockt fulfilled in 2014 under the umbrella of COST action “Mapping and the Citizen Sensor” directed by N. Kerle.

- creation of websites or use of other systems related to social networks in order to launch search surveys of images and share resources freely collected by the public.

- trigger training campaigns aimed at volunteers and tourists with cultural interests to achieve minimum levels of competence for the acquisition of overlapping images in order to obtain sets of stereoscopic images that completely cover the objects of interest and that are suitable for 3D reconstructions.

It is necessary to be aware of the fact that to date the generation of 3D models, despite the availability of automated tools, such as the SfM strategy, is definitely required for specialised software and trained personnel but certainly the use of these instruments has spread in many areas of specialists working towards heritage conservation. Furthermore, it is significant that alongside the consolidated commercial platform (Agisoft Photoscan has been the primary platform, Pix4Dmapper is currently very much used by the availability of tools for analysis and data processing that others do not have), a growing number of open source solutions are available. An extensive list of open source solutions and perhaps not entirely complete or updated is available at SfM Wikipedia entry. Some of these software require elevated skills or they need a combined use to cover the entire workflow of an SfM model generation.

Experimental Section: The Vank Cathedral in Isfahan in Iran

The Test Case

The application experience that we report simulates the opportunity given to the third point of the preceding paragraph. The work is intended for the generation of a 3D model and the evaluation of its potential, starting from basic data that may have been collected by volunteers trained to collect images suitable for 3D modelling.

Therefore, this experimental section focuses on the documentation of the Vank Cathedral in Isfahan in Iran; it is a building of the Safavid epoch (cent. XVII-XVIII) that is an age within the architecture, and especially the architectural decoration reach their peak since the interior of the cathedral is enriched with extremely relevant decorations of frescoes (see Figure 2). (Haghnazarian 2006)

The Vank Cathedral was one of the principal holy places that has been established in Isfahan by Armenian immigrants settled by Shah Abbas I of the Safavid Dynasty after the Ottoman War. (1603–1605). Tens of thousands of immigrants settled in the Iranian provinces towards the south of the Aras River, as well as relocated Armenians, who had fled from the Ottoman genocide and settled in the New Julfa quarter, which was named in memory of their original homeland. (Pasdermadjian 1990)

The Vank Cathedral (began in 1655 and ended in 1664), despite its small size, has the classic structure of the "domed hall" with double shell like the Persian mosques and longitudinal plan with a semi-octagonal apse. The migration of Armenians to Isfahan is essential to mark the turning point. This fact promotes the development of innovative formulations of Iranian art that combine with Armenian and Western naturalistic works.

The experience applied to the church focuses on photorealistic reconstruction of the interior surfaces by orthophoto applications derived from the SfM algorithms in "stereoscopic" mode. The photographs were taken with a professional digital camera and the high-resolution overlapping images of the frescoed surfaces were acquired in order to obtain a large scale model of the decoration details. The use of topographic measurements of the control points has been specifically avoided with the aim of simulating the acquisition by non-experts, devoid of topographical measuring instruments.

Figure 1. A view of the exterior of the church, very similar to a mosque.

Figure 2. The beautiful frescoed walls of the Vank cathedral with the highlights of some critical elements for photogrammetric processing: the presence of chandeliers and transparent protections at visitors' heights.

Data Collection and Processing

All phases of a photogrammetric survey process, from the collection of images until the restitution of realistic materials, are strongly dependent on the shooting strategy and on the spatial position of cameras. Despite this, the complete coverage of all parts of the object, the stereoscopic overlap of 80–90 %, and possibly shooting a different scale images are quite easy, and do not seem to be hard to teach the fans of crowdsourcing for heritage protection.

The characteristics of the used camera are reported in Table 1, while the software used was PhotoScan by Agisoft, as it is perhaps most widely used in the CH applications.

Table 1. Camera parameters for Nikon D7100. Complete datasheet available here: http://imaging.nikon.com/lineup/dslr/d7100/spec.htm

Lens	Nikon AF-S DX NIKKOR	focal distance 18 mm
Pixel size	0.004 × 0.004 mm	
Sensor	24 × 36 mm	6000 × 4000 pixel

About 200 shots were been acquired to fully cover the internal walls of the central room and the apse. A long series of nadiral upwards images (with the camera resting on the floor) were distributed along the longitudinal axis of the cathedral, together with two other stripes perpendicular to the first in correspondence with two symmetry axes of domes. The acquisition distance for the selected camera is about 3 m; this usually ensures that the appropriate architectural scale of the survey is 1:50. Such a distance provides a Ground Sampling Distance (GSD) of about 0.6 mm. These parameters are obviously valid for frames with horizontal optical axis. Since the image collection was simulated by volunteers and tourists, no devices to raise the camera were provided. So, images have been taken using three different inclinations on the vertical axis of the "domed hall", and a vertical overlap of about 30% has been secured.

The experiments to obtain the overall photogrammetric block have been numerous. The encumbrances shown in Figure 2 (the chandeliers and the transparent protections) create either problems in the recognition of the tie-points or high levels of noise in the cloud, and they have been previously masked.

In the end, the best way was to calculate two photogrammetric blocks divided into the two main areas of the church. The nadiral image stripe acquired along the central axis of the church made it possible to achieve the union of the two blocks in a single project, and therefore get a single cloud that represents the entire interior of the cathedral.

The latter result, that of a single cloud, was essential to associate the appropriate scale to the model. In the absence of control points, two linear distances that are easily measurable on site, have been collected (see Figure 3) in order to be given as a constraint to the photogrammetric block in order to calculate the scale factor of the model.

The overall result has been the achievement of a point cloud that in terms of accuracy was not so much different from the many applications made with the use of the control points. The residuals were slightly higher, but settled around 2 cm.

The data analysis has been made using the software 3DReshaper by Technodigit, mainly for converting the point model in a continuous surface (mesh) and in order to achieve the model optimisation and the projection of the textures with the help of the oriented images (filtering the cloud, closing the mesh lacks etc.; see Figures 4 and 5). PointCab was rather the software used to make sections of the cloud with significant planes with the aim to realize Autodesk AutoCAD architectural drawings together with the integrated orthophotos (see Figures 6 and 7).

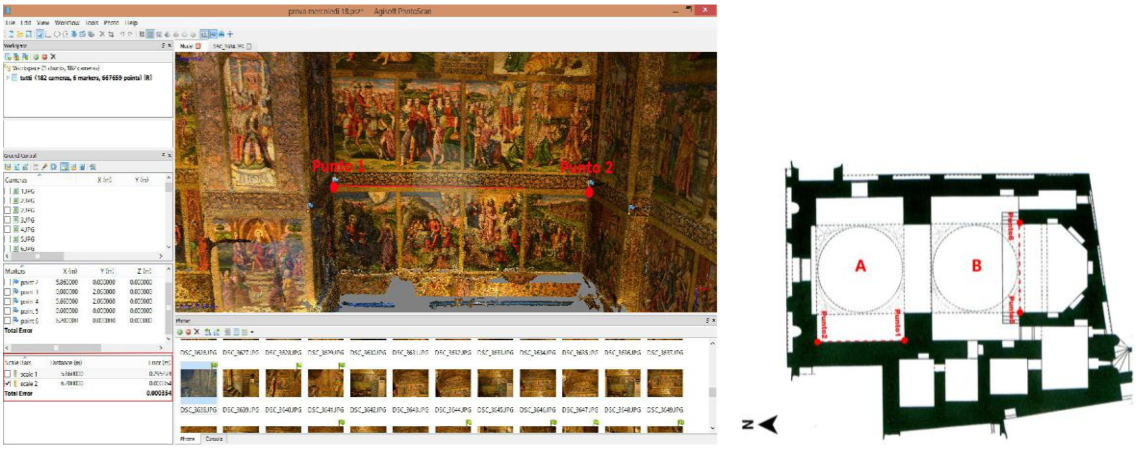

Figure 3. The two direct measures of distances on which we based the calculation of the model scale.

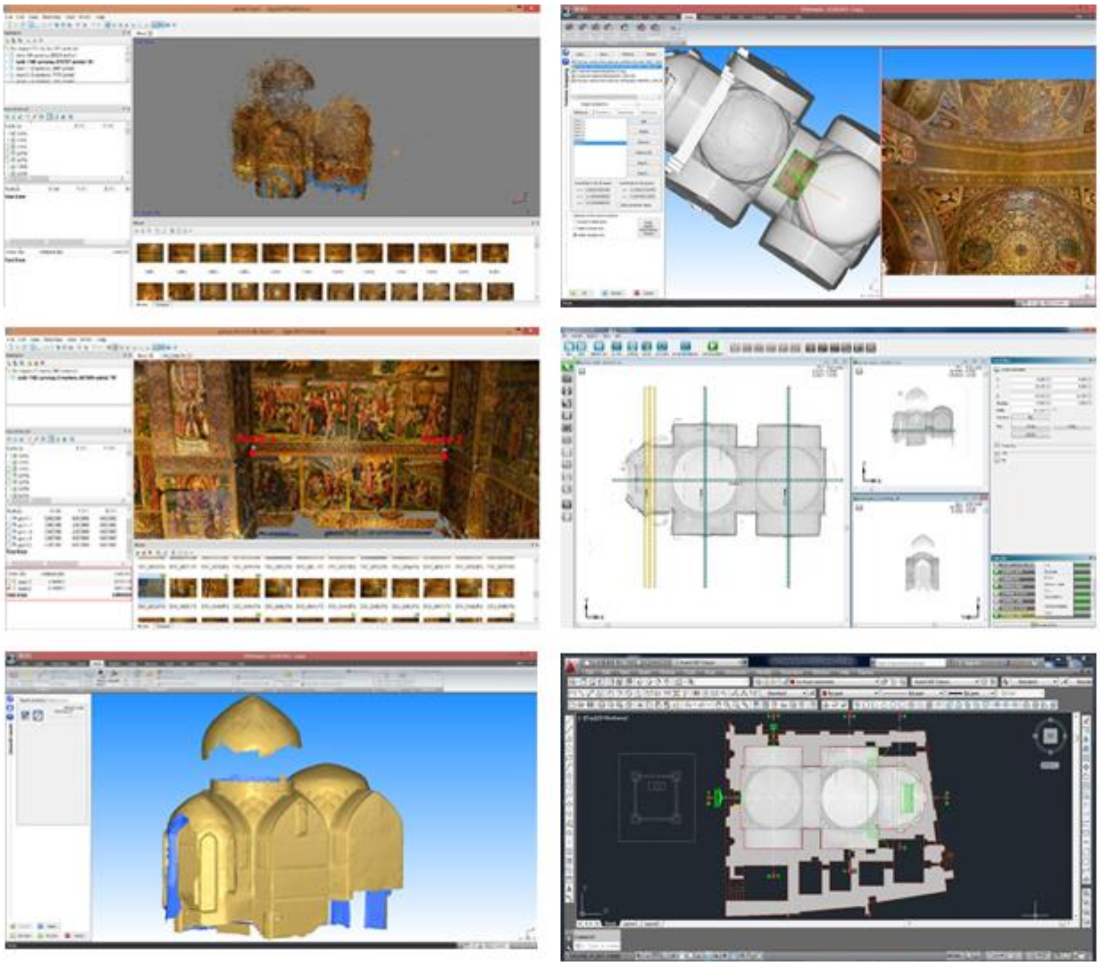

Figure 4. Some phases of the SfM workflow and the consequent processing aimed to obtain 2D and 3D representations.

Figure 5. The entire meshed model with high-resolution textures representing frescoes; the lack of surface above the drum of the dome is obvious due to the impossibility to take pictures.

Figure 6. The complete vaults orthoprojections superimposed on the upwards plan.

Figure 7. Some examples of 2D architectural drawings with orthoprojections of frescoed walls and vaults.

The Mosaic of Orthophotos for the Interpretation of the Frescoes

Since the Vank cathedral is considerably featured by a new style in its time because of the combination of cultures, religions, styles, and iconographical formulations of various styles, especially in the field of interior decoration of the frescoes, the orthophotos have a preeminent role in this project. The interior walls of the Vank Cathedral were decorated with the 113 scenes arranged in five registers of the history of the New and the Old Testament, and also the story of Saint Gregory "Illuminatore" (Armenian *Lusaworič;* according to the tradition, he is the founder of Armenian Christianity)—the sense of reading from right to left starting from the apse.

According to one of the main goals of the project, the image-based model has been used to develop the representations of the walls surfaces in a single continuous image (the mosaic of several orthophotos) to continuously read the development of the decorative cycles. The orthophotos support the deep understanding of the liturgical sources of the frescoes; in fact, it is possible to focus on the composition and the iconographic reading of the large fresco cycles covering the entire stretch of the interior facades. This interpretation of the frescoes provides the possibility to recognise a new style for understanding the Armenian art in the Safavid period. In another publication (Hashemi and Nourollahichatabi 2015), a comparison has been attempted between the depictions of the Last Judgement of the Vank Cathedral with that of Franghias Kavertzas (XVII century, Venice) and that of Michelangelo, which is already the subject of specific studies. (Angheben 2006)

The variety of subjects treated in the frescoes cycles is perhaps understandable from the list below, which corresponds to the identified cycles in Figure 8:

- Images from the life of the prophets (from 1 to 8);
- Episodes of the Old Testament stories (from 9 to 34);

- Episodes of the New Testament stories (from 35 to 60);
- The episodes of the Yahya murder, the miracle of Christ and the death of Mary (from 64 to 74);
- Miracles and stories of Christ (from 75 to 85);
- Episodes from the life of Saint Gregory (86);
- Description of seven sacred rites (from 107 to 113);
- Apocalypse;
- Heaven and hell – the seven floors of heaven;
- Christ and the apostles;
- Prophets before Jesus.

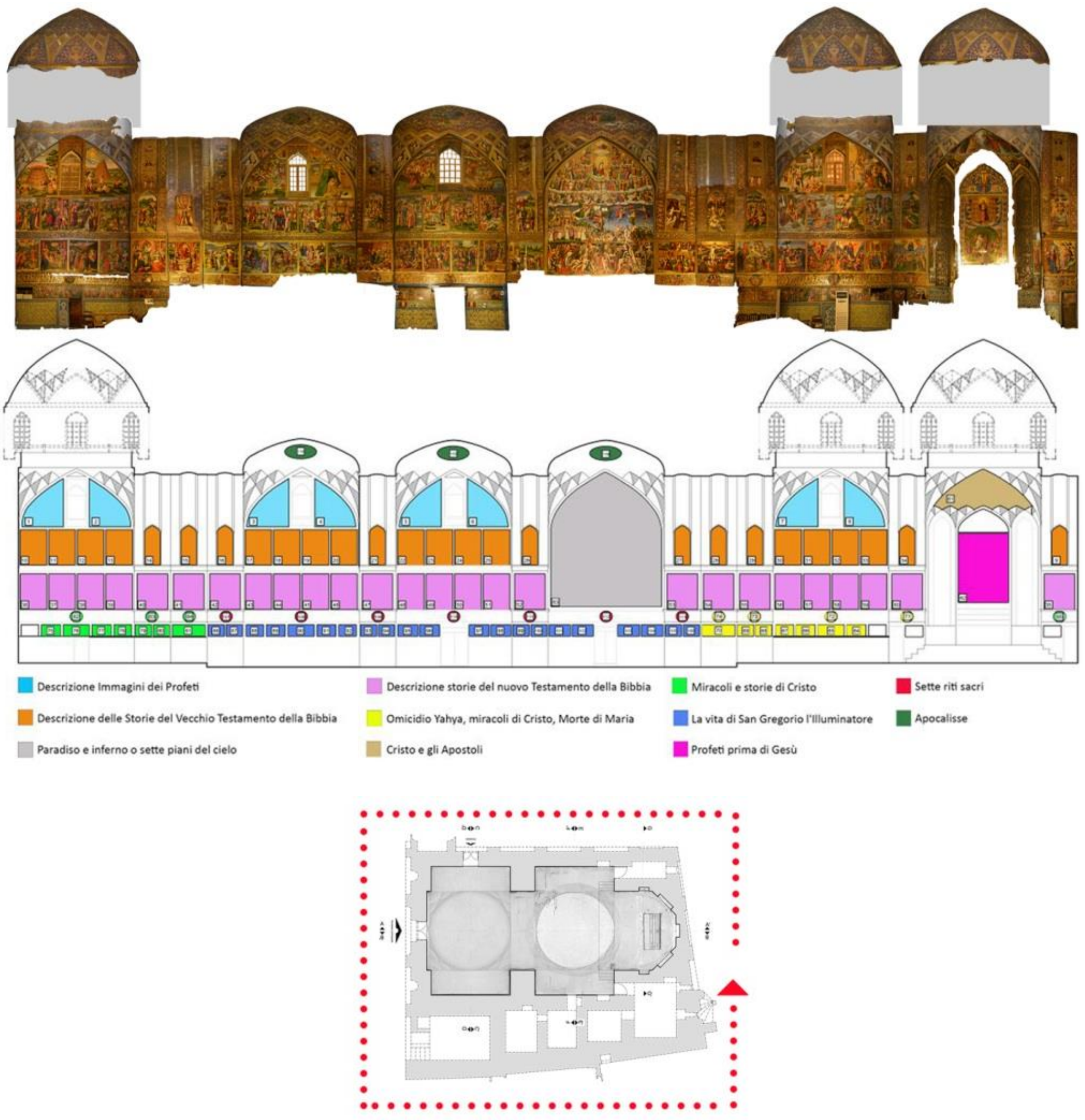

Figure 8. Compositional scheme of the various registers of the frescoes of Vank Cathedral represented by unique image composed by a mosaic of orthophotos.

An Example of the Iconographic Reading of the Frescoes: Ascent to Calvary

We propose an example to prove that orthophotos allow and facilitate the iconographic reading of the frescoes and thus support the reading and the analysis of metric and radiometric information. According to some general and established principles to read the iconography of sacred representations (Goldammer 2006), we selected a part of the third register of frescoes, which consists in seven scenes of Jesus' Passion explaining the story of the last events of Christ's earthly life from the episode Way to Calvary to Descent of Holy Spirit.

The iconic Ascent to Calvary is one of the episodes of the narrative scenes that presents how Christ, carrying the cross, has been aided by Simon of Cyrene and is surrounded by a crowd of spectators and soldiers.

In Figure 9, we have outlined that the composition of the fresco comprises an isosceles triangular element that divides the entire scene into three parts: the main character is located in the third part of the scene. In addition, the depth of the painted work is distinguished according to the importance of the characters; it has been pointed out with the use of various colours. In particular, the composition of the Vank cathedral frescoes shows a traditional structure, such as the Byzantine style, while the Western Renaissance painting style imprints dynamism of the composition along with the most advanced use of perspective, in order to create the appearance of depth.

Later, the representations of the Passion of Jesus, respectively of the Vank Cathedral, the painting by Duccio di Buoninsegna (we retrieved the picture of figure 9 from an online repository, http://www.artbible.info) and the one by an unknown Flemish painter (picture of Figure 9 retrieved from the Metropolitan Museum of Art on-line repository, http://www.metmuseum.org) have been compared. It is possible to notice the immobility of the figures in the painting by the painter from Siena, while the Armenian culture has a movement that is likewise adopted by the flamingo painter. In the last one, the background is entirely occupied by an urban view, which provides movement and reality of the scene.

In the light of these and many other comparisons (Hashemi and Nourollahichatabi 2015), we can assert that the most obvious characteristics of the Armenian art of the frescoes in the Vank Cathedral is an innovative combination with intermediate characteristics, which derive from western styles and are under the influence of Armenian and Persian traditions in the Safavid era.

3D Printing Technologies in Reconstruction of CH

Nowadays, the advent of 3D printers has opened up new horizons in the heritage field since 3D printing technologies offer wide opportunities in the reconstruction of objects domain, and the purposes connected to research, documentation, preservation and education are rapidly developing. Due to the increasing demand within the humanities and social sciences for the use of crowdsourced digitising of CH and the development of digital data capture technologies, the printing of 3d models of real objects are increasingly used to develop 3D data visualisations.

The 3D-printing process consists of three steps: creating a 3D model, changing that model into a file that can be executed on a 3D printer (a process known as slicing) and finally loading the model on the printer and having it printed. This paper does not intend to enter into the debate of using 3D printing for cultural heritage, or even to describe the procedural or critical aspects of the press, or even the benefits of different 3D printing systems.

Assuming that simplified and suitably schematised models can be printed and used in a didactic environment, such as the knowledge dissemination intended by the museums and other cultural institutions, we are going to present another outcome of the Vank cathedral image-based model.

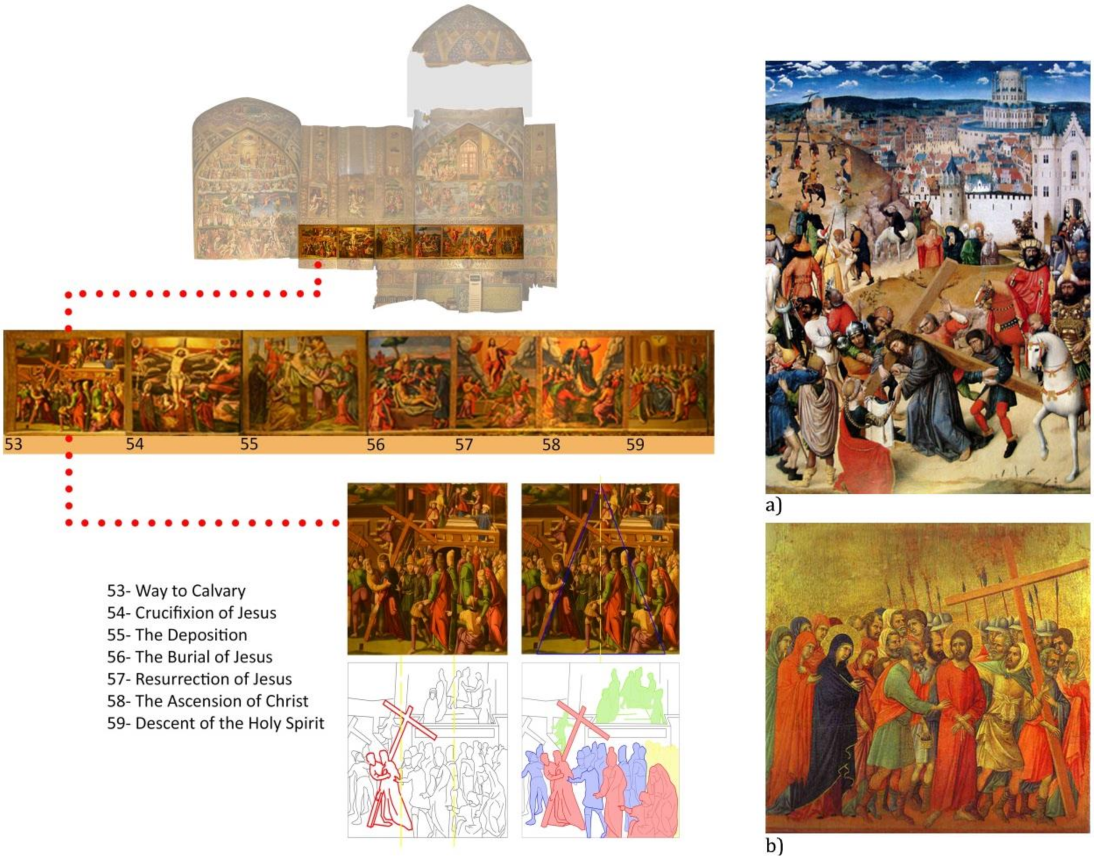

Figure 9. The analysing and the reading of the fresco ascent to Calvary. In the right: a) North Netherlandish Painter, Christ Bearing the Cross, 1470, Metropolitan Museum of Art, New York; b) Duccio di Buoninsegna, Maestà (recto), Road to Calvary, 1308–1311, Museo dell'Opera Metropolitana del Duomo, Siena.

The Vank Cathedral 3D Printed Model

The printed 3D model of the Vank Cathedral has been realized for easily communicating the geometry of the volume, the proportion of the walls, the vaults and the general structure. Of course it was necessary to complete the model in the missing parts (the cylinder under the dome and the lower portions of the walls covered by the transparent protection), and we aimed to build a printable model of half of the building, since the studied and significant part was the inside of the building. Such a half 3D printed model is able to refer to architectural features and proportions of the general composition of the building; so it can be compared with other samples.

After a large comparison with other Armenian Churches outside Iran (Cuneo 1989), the Holy Cross church is to be examined. This church on Aght'amar Island in Turkey's Lake Van is a medieval Armenian Apostolic church. It was built in the 10^{th} century (915–922) with the dimensions for the interior space as 14.80 m by 11.5 m and the height of the dome as 20.40 m. The architectural style of this church has been influenced by the architectural style of Saint Hripsime (Der Nersessian 1974).

On the other hand, the Vank cathedral has a rectangular plan (19.50m by 10m) with two different sizes and shapes of domes covering the two parts of the church. The domes of the church reach the height of 17.50m and 12m thanks to the effective use of overlapping bricks typical of the Safavid architecture. They adopted a quadrilateral arch, which provides a double shell like the domes of mosques.

In Figure 10, the scaled 3D printed models can be explained to the public in this way that these two churches, even if religious, artistic, symbolic and other relations connect them or even if they present more or less the same proportional relationships, they are featured by different constructive systems. So in this respect, the domes are very different.

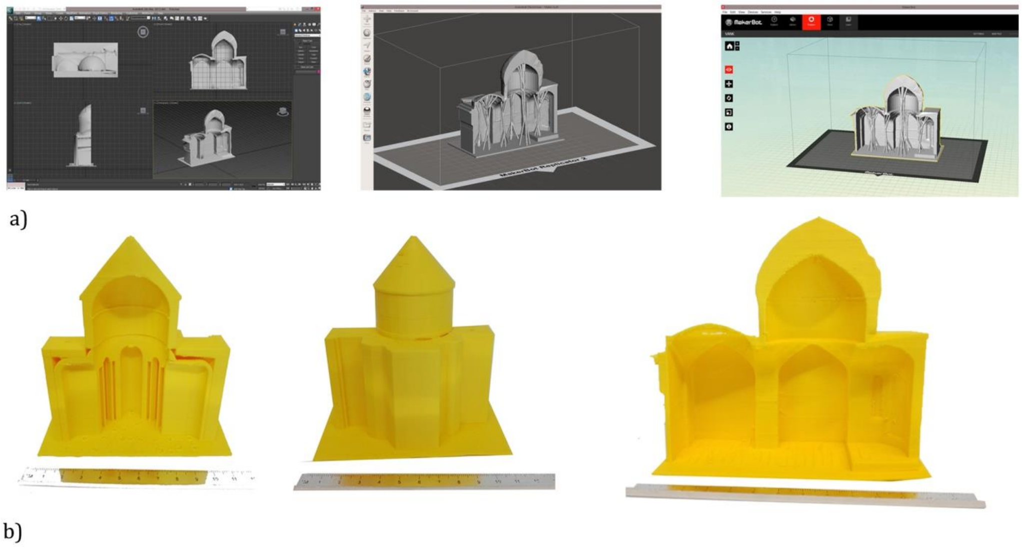

Figure 10. a) The reconstruction of semi volume with 3D-Modeling Software for the production of 3D printed model (3D Studio Max, Meshmixer, MakerBot Desktop) ; b) 3d printing models of the Church of the Holy Cross and of the Vank cathedral.

Conclusion

We believe that the results of this project leads in two different directions. The first is that now an accurate and a detailed, comprehensive documentation of the interior of Vank Cathedral is available.

Other considerations regarding the objectives, to which the new technologies can be addressed, are, if possible, more relevant. Actually, this test case is even a pretext to discuss the current opportunities to enhance the crowdsourced collection of image data concerning the Cultural Heritage scattered in the world with the aim to derive spatial data and models.

Starting from the consideration that recently the extensive prevalence of crowdsourcing activities and public participation in the CH domain as gathering, categorising and maintaining heritage collections has increased, the application of 3D technologies based on crowdsourced resources can be encouraged and developed.

If it is true that during the recent years, the image-based models have provided impressive results for cultural heritage, with an effective impact on preservation, valorisation and heritage documentation, it is undeniable that the accessibility of an accurate digital representation allows several possibilities of utilisation to the specialist or to ordinary people.

This is the reason why this research project employs a crowdsourcing strategy to collect images by non-specialists; the results of the test provide 2D architectural drawings and the high resolution photogrammetrical orthoprojection of frescoes adding to 3D digital model that can be effectively exploited by many specialists involved in CH conservation.

Lastly, today, we are all convinced that 3D printing technology can be earmarked for communication and dissemination projects to a broad audience, but the debate on the possibility of different uses is definitely alive.

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