

PAPER • OPEN ACCESS

Immersive Virtual Reality As A Resource For Unaccessible Heritage Sites

To cite this article: Giovanni De Gasperis *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **364** 012035

View the [article online](#) for updates and enhancements.

Related content

- [3D data integration for the digital reconstruction of cultural heritage monuments](#)
Laura Micoli, Sara Gonizzi Barsanti, Umair Malik et al.
- [Virtual Reality Website of Indonesia National Monument and Its Environment](#)
B A Wardijono, F Hendajani and S A Sudiro
- [Enhancing cultural tourism by a mixed reality application for outdoor navigation and information browsing using immersive devices](#)
Federico Debandi, Roberto Iacoviello, Alberto Messina et al.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Immersive Virtual Reality As A Resource For Unaccessible Heritage Sites

Giovanni De Gasperis, Alessio Cordisco and Francesco Cucchiara

Department of Information Engineering, Computer Science and Mathematics
University of L'Aquila, ITALY

E-mail: giovanni.degasperis@univaq.it

Abstract. This contribution highlights the potential contribution that modern technologies offer for virtual reconstruction and immersive navigation of monuments that are unavailable due to catastrophic events or other causes. We propose a design and implementation methodology for the enjoyment of the Cultural Heritage sites through three-dimensional and photorealistic modeling, visualization and rendering in a immersive virtual world enriched with extra content. The project of virtual reconstruction of monuments damaged by catastrophic events arises from the need to continue to enjoy the architectural asset during the stages of safety-laying, reconstruction and finishing, large-scale interventions that usually take a long time, especially for buildings belonging to the Cultural Heritage. The experience of the earthquake in L'Aquila of 2009 has reflected on the importance of Heritage and collective identity that changes whenever a cultural asset is not used anymore. Santa Maria Paganica in Virtual Reality Project implements a freely navigable virtual model able to let discover and rediscover one of the monuments of L'Aquila, damaged by the 2009 earthquake, which during the past had a most important role for the social, economic and cultural life of L'Aquila people, and that stays still today, 2018, not reconstructed. Here we present the results and the methodology of the process which allowed us to get a model available in a immersive virtual reality environment. The chosen VR engine is the Unity software, which allows to implements models compatible with the two most common adopted VR headsets: HTC VIVE and OCULUS RIFT. The final VR artifact is an executable software like a videogame, playable on a PC; virtual lighting systems have been projected in order to get a better graphic performance avoiding to alter the mesh model, and the navigation system in VR has been implemented with specific C# scripts.

1. Introduction

This virtual reality experimentation is focused to a monument of the city of L'Aquila. On April 6, 2009 a Mag 6.3 Richter earthquake hit the city that destroyed most of the civil, residential and religious buildings. Even today, 2018, some areas of the historic center are still forbidden to the public and many monuments, which characterize the historical city center, are uninhabitable and inaccessible. The importance of the Heritage for the collective identity is undisputed; this link was reiterated in the Council of Europe Convention, adopted in Faro in 2005, which attributes to the Patrimony a strong social value recognizing it as the foundation of a democratic society, in which the community creates and reaffirms, through a common cultural heritage, a civic sense of belonging [1]. Nowadays modern technologies are commonly adopted by the scientific community and they constitute important tools for the reconstruction of memory, use and enhancement of inaccessible or no more existent Cultural Heritage sites destroyed by anthropic or natural



transformation. Significant is the worldwide interest in the Syrian site of Palmyra, destroyed by ISIS in 2015, virtually rebuilt and now accessible via the web [2], being the subject of much research and experimentation [3; 4; 5]. A very interesting Italian example is the one carried out by the research team of the University of Bologna (Ravenna) on the church of Santa Maria del Porto outside, destroyed by the bombings of the Second World War and never rebuilt [6]. In the context of the post-seismic reconstruction activities carried out in the crater ¹ territory, there are many research projects on Heritage that adopted modern technologies: starting from remote surveying in the emergency phase with UAV technologies and laser scanning [7; 8], up to the use of the thermal imaging camera [9], from digital photogrammetry of civil and religious buildings [10; 11; 12] up to the modern BIM trials [13; 14; 15]. These are all functional digital tools, generally aimed at the documentation of the damage and the state of the artifact at a specific time and the restoration projects of the heritage, where possible. However, there are still few technological applications for the enhancement and fruition of heritage, as the interesting projects that have been undertaken both by private individuals, as in the case of the enhancement of the Aterno valley [16], and by public bodies, such as the National Museum of Abruzzo, who digitized part of his collection making it public on the SketchFab online platform [17]. Therefore it was decided to carry on the VR experimentation on the church of Santa Maria Paganica, symbol of L'Aquila history and very dear to the inhabitants.

2. Case Study: The Church of Santa Maria Paganica in L'Aquila

The city head quarter of Santa Maria Paganica, one of the most significant monuments of the Aquilan area, is full of architectural superficies and stylistic stratifications that can be correlated with the many historical earthquakes that have hit the city over the centuries. Probably the structural interventions made in the past have compromised the stability of the building causing most of the damage by the earthquake of 2009: collapse of large part of the roof and the dome, the side wall and the facade [18] (Figure 1).

The earthquake, however, also brought to light unpublished architectural elements, reused in the walls, which document the past of this building, such as the Gothic inscription, found during the recovery of the rubble, which testifies the post-earthquake reconstruction of 1349 [19]. In fact, the original building, built in conjunction with the birth of the city at the behest of the inhabitants of Paganica village who first settled in this site, was very different from eighteenth-century (post-earthquake 1703) visible today characterized by a single-nave plant with noble chapels, a large transept in the presbyteral area surmounted by a majestic dome and semicircular apse. The building has a majestic facade, referable to the original plant as witnessed by the date 1308, in tanning stone with horizontal crowning and a mighty bell tower, attributed by many scholars to a pre-existing fortification that stood on the highest point of the city [20], which was later lowered by an edict of the Spanish rulers in the XVI century.

3. Methodologies and technologies for the Cultural Heritage

Before engaging in the virtual modeling of the church, we conducted studies aimed at the knowledge of the monument, as well as previous documentation for the retrieval of the graphic and photographic material prior to the 2009 earthquake; in addition to the study of the published material and private collections, we tried to record the historical memory of those who knew and visited the artifact in person; in this regard the parish priest Don Stefano Rizzo gave the most significant contribution making available, not only the photographic archive, but also its visual memory necessary for the reproduction of elements not photographed and/or digitized in the past. Furthermore, inspections were carried out on the outside and inside the building, indispensable for carrying out the photographic sampling and the measurements of the surviving

¹ the term refers to the area legally affected by the seismic event



Figure 1. Church of Santa Maria Paganica after the 2009 earthquake (photo available online).

environments with direct survey techniques. All the photographic material recovered has been analyzed and divided into two groups: monochromatic and color, using the black and white ones as the basis for the modeling, while the others reproduce the chromatic range of the walls, floors and furnishings. Subsequently, we carried out the virtual modeling in VR of the church, following the criteria proposed in the London Charter [21], that we translated into integrating different methodologies and technologies such as digital photogrammetry, three-dimensional modeling, rendering and assembly in the gaming editor. We have chosen to use photogrammetry to document and make usable only for those part of the architectural elements and liturgical furnishings that survived the earthquake; it was possible to recover a large amount of documentation material, but unfortunately not enough to reconstruct the whole building in detail. Particular attention was paid to the lateral portal and baptismal fountain base: we processed them with the Photoscan software by Agisoft, giving us respectively a digital model with a mesh of 1'801'062 faces, while the latter has a more accurate model with a mesh of 2'590'334 faces (Figure 2). The accuracy of the mesh needs to take into account the strict specification of the real time rendering during the VR session.

These meshes are generated from a set of images acquired in emergency conditions with suboptimal light exposure and noise elements; the raw results were very complex and not easily managed and therefore reworked within the Cinema 4D software to obtaining "clean" models that can be easily assembled with the 3D model of the church in a Unity scene. For the modeling phase, several software were used: SketchUp for basic modeling (Figure 3), Cinema 4D (Figure 4) for details and Lumion for video rendering. Adopting a 1: 1 scale plan and a side elevation representing the church as a base, we proceeded to create the perimeter walls, the openings, the noble chapels and the vaulted roof. The raw model created in this way has been modified several times until we reach a structure as faithful as possible to reality of the pre-earthquake situation. In some cases, using the photos as a basis, it was possible to reproduce models likely to be real, while in others, due to the absence of support materials, the elements are less accurate, but with

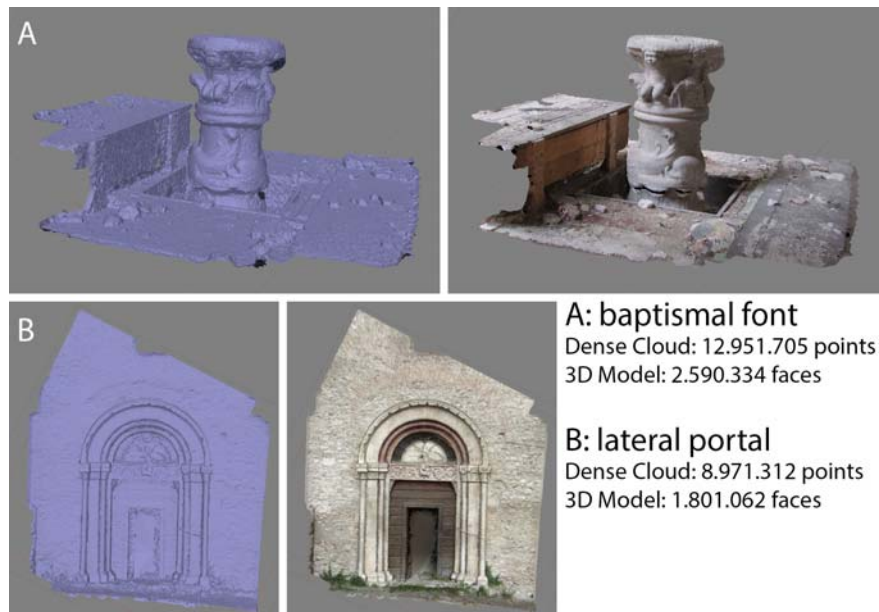


Figure 2. Photogrammetric models : (A) baptismal fountain base; (B) lateral portal.

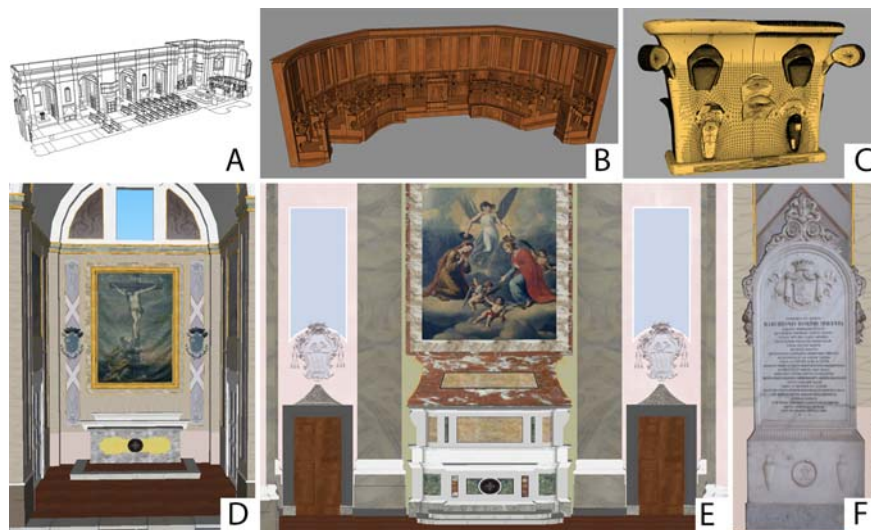


Figure 3. Examples of elements modeled with SketchUp software: A - wireframe of the entire structure; B - wooden choir; C - capital; D - first left side chapel; E - transept; F - funerary tombstone

all the distinctive and distinguishable features.

Once the overall model was obtained, the modeling work focused on the details: capitals, pillars, cornices, altars, etc.; a very long process that led to the creation of 108 components collected in 12 groups, to which 211 images were used as surface textures. The extension of the building, the complexity and the richness of the furnishings led to a choice of representation, depicting some elements in 2D, such as the statues inside the niches and the decorative element of the top part of the three portals; to these two-dimensional objects, in the rendering phase, a normal map was applied to produce the relief effect and 3D. Attention was mostly reserved to the inner part of the building, unfortunately today destroyed; also to enrich the morphological context were to put the virtual church, we reproduced a minimalist square and the volumes

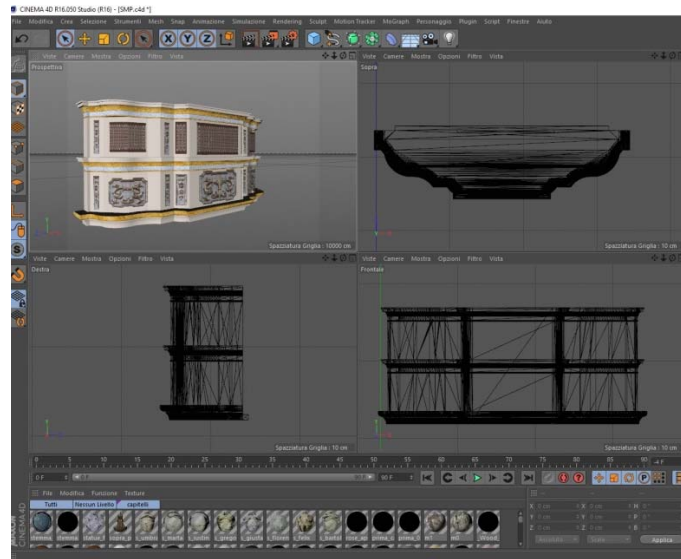


Figure 4. Modeling of liturgical elements in Cinema 4D software.

of the neighboring buildings, leaving important details for lack of time, such as the fountain and the terrain orography. As a final stage, we performed the rendering of the inside using the Lumion software, generally used for architectural visualization, which allowed us to obtain photorealistic rendering, 3D video and VR panoramas in a shorter time compared to the main competitors (Figure 5).

We adopted different tools for the further visualization of the model of the church of Santa Maria Paganica, from the conventional ones, like images and videos, to the most innovative ones like spherical 360° images linked together to form a virtual tour from specific landmark positions. However, these are rendering systems that constrain the user mobility in the model, not leaving much freedom of movement.

4. The Virtual Reality Implementation

4.1. Scene description

Geometry : the scene has approximately 300 meshes, more than 1 million polygons and 130 PBR (physically based rendering and shading) materials using the standard shader in Unity that is quite computationally expensive. **Lighting** : since the geometry is very complex and the scene's objects are static, the best solution would have been to use a pre-calculated baked lighting system. But we decided not to do. Anyway baking such a large scene takes a lot of working time, so in this project we used two types of less computational intensive light models (ambient and directional) plus a spotlight to be used as a torch by the user only when the player needs it where she wants. **Post Effects** : the first notable thing in this VR scene was a strong aliasing effect. To avoid it we used a 8x multisampling antialiasing (MSAA), which is available only in forward rendering. Thanks to MSAA almost all the aliased edges were correctly smoothed and the users were not distracted any more by that unrealistic graphic behavior. Another useful post-effect we added to the rendering is the screen-space-ambient-occlusion (AO). The scene acquired a good realism as a result of this combined effects because the dynamic shadowing system only projected direct shadows on the scene's surfaces.



Figure 5. Virtual reality walkable model of the Santa Maria Paganica Church. A demonstration YouTube video is available at <http://youtu.be/G5Tf1Jv88gA>

4.2. User interaction

The user must be able to move freely and interact with the virtual environment. Since a monument can be wide and very high, it can show interesting points in usually inaccessible areas. For this reason the movement system makes sure that each interesting point can be easily visited. The navigation experience is composed by 3 main actions: physic movement, teleport and torch control.

Physic movement: recent VR headsets provides position tracking, allowing the user to move freely in the virtual space. Unfortunately in most cases the available physic space isn't enough wide to explore the whole scene, so it is necessary to expand the movement range.

Teleport: the user should be able to instantly teleport herself to another area and explore it in the local physic space. The teleport system forces the user to first choose a destination point on the ground or on a floating platform and then activate the teleportation process. In this way the induced sickness side effect is completely avoided.

Teleport with controllers (tested on HTC Vive): we used the plugin Vive Teleporter by *FlafLa2* (<http://github.com/FlafLa2/Vive-Teleporter>) to create the teleportation system, similar to what is available in the “*The Lab*” VR game included with the headset. This plugin allows the user to choose destination points using a customizable parabola coming from one controller. The plugin uses a multi-raycast system to check collisions along a parabola. In order to setup a correct collision behavior it is necessary to create a navigation mesh that defines the areas in which the teleportation is allowed (we call these walkable areas). The system accepts the teleports on walkable areas and rejects the ones on non-walkable areas. Of course, to create a good navigation mesh it is essential to create a proper collider mesh. In our case, the original church model was very complex so we created a separated low-poly collider mesh. Using this method it is possible to move around an almost flat area, depending on the navigation mesh settings and on the parabola range, but sometimes it is not possible to reach a point of interest point because in the parabola may falls down before it can collide with it. Since one of the exposed parabola properties is the gravity to which it is subject, it is possible to reduce it to 0 and transform the

parabola into a straight line that can potentially reach each point of the space. We modified the original script adding a straighten parabola mode to be used only when there is an intent of reaching a higher walkable area. The reason we did not use everywhere just the straight line is that the parabola is a much more natural way of selecting a destination point especially for large distances, because it does not allow the user to point towards areas that are too far from her.

Teleport without controllers (tested on Oculus Rift) : without space-tracked controllers the only useful device for the dynamic selection is the headset, so we implemented the teleport system to make it follow the head movement. In this case the only option possible is the straight line and the user has an always visible dot in the view centre that represents the gaze line's direction. All the inputs are from static controllers. In this case the valid/invalid areas are managed by a tag. The system checks whether the collider's tag corresponds to the ground or an obstacle and returns the user a yellow (valid) or a red (invalid) indicator. The line in this case is not visible and it virtually extends to the infinity, so there is no problem in reaching high interest points.

Dynamic torch behavior In some areas of the 3D environment the combination of ambient and directional light does not produce enough illumination. For instance, a crypt with a picture in it should be enlighten to let the user see the affresco that is inside of it. But having point lights near each interest point could be too expensive for the real time rendering of a complex scene, so we decided to create a torch system the user can activate to bring light to specific areas of the scene. The torch should be handled by a space-tracked controller when possible. If so, the light direction should follow the controller orientation but if there is no controller available the only way to illuminate what the user wants is to make the light direction follow the headset orientation. Also, the light should adapt its range in relation to the distance that is found from the object(s) which are under observation.

5. Conclusion

We demonstrated a quasi-philological virtual reality reconstruction of a church badly damaged by a strong earthquake using the most advanced consumer grade VR technology. We showed that it is possible to make the inaccessible, (virtually) accessible again. Such virtual reconstruction can only give back a living memory for Cultural Heritage sites that have a strong bond with a local community, while the real bricks and mortar reconstruction can get started and hopefully end by the life time of those who remember how it was.

6. Acknowledgments

This work was carried out with internal funding from University of L'Aquila. We thank Prof. Piero Tognolatti to encourage us to pursue on this project and Prof. Silvia Mantini for insightful historical discussion about the Church of Santa Maria Paganica in L'Aquila.

References

- 1 Convenzione quadro del Consiglio d'Europa sul valore dell'eredità culturale per la società, Consiglio d'Europa - (CETS no. 199) Faro, 27.X.2005.
- 2 <http://www.newpalmyra.org> [Last accessed 22 Dec 2017]
- 3 Wahbeh W, Nebiker S and Fangi G 2016, Combining public domain and professional panoramic imagery for the accurate and dense 3D reconstruction of the destroyed Bel temple in Palmyra, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. III-5:81-88.
- 4 Arkawi A 2017, Vision of the reconstruction of destructed monuments of Palmyra (3D) as a step to rehabilitate and preserve the whole site, The International Archives of the

- Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XLII-2/W5: 41-48.
- 5 Denker A 2017, Rebuilding Palmyra virtually: recreation of its former glory in digital space, *Virtual Archaeology Review*, Vol. 8-17: 20-30.
 - 6 Volpe A 2017, Una mostra sulla distrutta chiesa di Santa Maria in Porto Fuori, *Bollettino dantesco*, 6 settembre 2017: 139-154.
 - 7 Baiocchi V, Dominici D and Mormile M 2013, UAV application in post-seismic environment, *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XL-1/W2: 21-25.
 - 8 Pesci A, Loddo F, Casula G, Zampa F and Teza G 2010, Experience in mobile laser scanning by means of lynx system in L'Aquila city, *INGV*.
 - 9 Cadelano G, Bortolin A, Cifan Gi, Ferrarini G, Mannella A, Petracca A and Bison P 2015, Ispezioni stutturali supportate dalla termografia IR, *Act of XVI Convegno ANIDS*, L'Aquila.
 - 10 Bartolomucci C and Trizio I 2015, Dal rilievo del danno sismico al disegno per il progetto di restauro: un'applicazione di documentazione speditiva in condizioni di emergenza, *DisegnareCon*, Vol. 8 n.14: 24.1-24.8.
 - 11 Giannangeli A, Marchetti A and Trizio I 2015, Dalla fotogrammetria digitale ai Pdf 3D: considerazioni sulle potenzialità offerte dalle metodologie di rilievo speditivo basate sullo SfM, *Act of XVI Convegno ANIDS*, L'Aquila.
 - 12 Dominici D, Alicandro M, Rosciano E and Massimi V 2017, Multiscale documentation and monitoring of L'Aquila historical centre using uav photogrammetry, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XLII-5/W1: 367-371.
 - 13 Brumara R, Della Torre S, Oreni D, Previtali M, Cantini L, Barazzetti L, Franchi A and Banfi F 2017, HBIM challenge among the paradigm of complexity, tools and preservation: the basilica di collemaggio 8 years after the earthquake (L'Aquila), *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XLII-2/W5: 365-371.
 - 14 Continenza R, Trizio I and Tata A 2017, Riscoperta del palazzo della famiglia Branconio in L'Aquila. Applicazioni BIM a un cantiere della ricostruzione aquilana, in *AAVV (eds) Territori e frontiere della Rappresentazione*.
 - 15 Continenza R, Redi F, Savini F, Tata A and Trizio I 2017, BIM for the Archaeology of Standing Buildings: Case Study of the Church of San Cipriano in Castelvechio Calvisio (L'Aquila, Italy). Fogliaroni P, Ballatore A and Clementini E (eds) *Proceedings of Workshops and Posters at the 13th International Conference on Spatial Information Theory (COSIT 2017)*. COSIT 2017 2017. *Lecture Notes in Geoinformation and Cartography*. Springer.
 - 16 <http://valledellaterno.it/torri-e-castelli> [Last accessed 22 Dec 2017]
 - 17 http://sketchfab.com/PoloMusealedellAbruzzo/collections/munda_museo-nazionale-dabruzzo-laquila [Last accessed 22 Dec 2017]
 - 18 Carocci C, Cattari S, Lagomarsino S and Tocci C 2010, The Case Study of Santa Maria Paganica Church Damaged by 2009 L'Aquila Earthquake, *Advanced Materials Research* Vol. 133-134 (2010): 163-168.
 - 19 Torrieri V 2010, L'Aquila, Santa Maria Paganica. Archeologia e rimozione delle macerie dopo il sisma del 2009, *Quaderni di Archeologia d'Abruzzo* 1/2009 (2010):65-69.
 - 20 Antonini O 1999, *Architettura religiosa aquilana*, Edizioni del Gallo Cedrone, L'Aquila.
 - 21 <http://www.londoncharter.org> [Last accessed 22 Dec 2017]