Virtual Cerrate: A DVR-Based Knowledge Platform for an Archaeological Complex of the Byzantine Age

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Abstract

The main aim of this study is to enable the public to enjoy the results of archaeological and archaeometric research, via the web or stand-alone products, and to "virtually visit" the monuments using RealTime 3D visiting systems. The navigation platform allows the user to visualise complex scenes and DVR-based knowledge models in "full-screen mode" even on desktop computers. As well as showing the current state of the monuments, the visit includes reconstructions of previous phases in their history and virtual restorations of the Byzantine paintings. All the textures were obtained by processes of photomodelling and were applied to the geometrical forms in accordance with the radiosity algorithm, with lights and shadows of the 'area' type. The result is extremely life-like, almost indistinguishable from reality.

Keywords

Virtual Reality, RealTime 3D navigation, 3D Laser Scanner, 3D Image-Based Technologies, Virtual Restoration

1. Objectives

The main objective of the Italian National Research Council's IbamITLab in the context of the ByHeriNet project is the development of integrated methods for the creation of three-dimensional models using laser scanning techniques, photogrammetry and 3D photomodelling, applied to Byzantine sites in the province of Lecce and the region of Basilicata, with particular reference to those monuments with elements of special interest that are representative of the period in question. The three-dimensional models developed using the integrated methods described below provide a useful knowledge base for representing architectural morphology on various scales with great accuracy. This includes both specific details and the overall monumental arrangement, as well as the textural characteristics of the interior and exterior surfaces.

Each monument was modelled and studied in relation to its environmental context, noting its underlying system of relationships, which is often the key to understanding the architectural strategies adopted. The main goal of this research however remains that of allowing the public to benefit from the results obtained, either via the web or stand-alone products, so that they may "visit" and enjoy the monuments using both 3D RealTime visiting systems and spherical and interactive 3D panoramas. Each three-dimensional model is thus integrated in a multimedia authoring system in which all the data formats available for the item in question (audio, video, VRML, QTVR, VR-Object, images, tables, etc.) can be combined in a single environment. Descriptions of an academic and critical nature (historical overview, relations with other ancient contexts, exegetical analysis, etc.) are combined with technical and scientific methods of analysis and diagnosis (e.g. analysis of constituent materials, state of conservation, study of architectural characteristics, etc.). In an interactive environment, it is possible to interact with the structures of the sites

Fig. 1. The Abbey of Santa Maria di Cerrate (Lecce, South Italy), real photo.

Fig. 2. Santa Maria di Cerrate (Lecce, South Italy), 3D reconstruction of entire abbey.

under study and search the associated Databases for drawings of the layout, topographical data, orthophotos and historical documents, together with information on the mineralogical and petrographic characteristics of the construction materials, plasters and paintings. The virtual visit is further enriched with CG (Computer Graphics) reconstructions that provide the user with a diachronic reading of the monument and enable him/her to better understand the transformations it has undergone.

The process of creating content relating to each monument studied may be summarised as follows:

1. Gathering of the historical documentation available;
2. Architectural survey of the structures, performed with methods appropriate to the distinctive characteristics of each monument;
3. Three-dimensional restitution and optimisation of the models in accordance with the predicted outputs;
4. Extraction of the two-dimensional maps and video footage to be integrated in the computer vision systems or in the stand-alone publishing products (DVD Videos, VRML models, etc.);
5. Creation of virtual spherical panoramas (QTVR);
6. Implementation of the 3D models and QTVR contributions in VR knowledge platforms.

2. Strategies for the restitution of the monuments in their current state

From the outset, the research team tried to identify methods that were suitable for a faithful recreation of the actual state of the items at the various scales, with a view to their publication on RealTime 3D platforms. The first element in the identification of the appropriate method is the detailed analysis of the objects under study. In our case, the ByHeriNet project entails the study of two main monuments: the first is the abbey of S.M. di Cerrate (Squinzano, Lecce, Southern Italia), located inside a monastic complex, characterised by fairly regular architectural spaces and elements, with plastic motifs associated mainly with capitals and the main doorway. Given the monumental arrangement and the size of the site, architectural photogrammetry methods were considered best for the three-dimensional restitution. The second monument studied is a rupestrian church carved out of a steep rock face near the ravine of Matera, a UNESCO World Heritage Site. The church is entirely excavated from the rock and is characterised by a rather irregular and organic pattern, with hollows and bulges that testify to continuous alterations over the course of the centuries. The architectural space is characterised by a certain continuity of the surfaces. Consequently the geometry that can best represent it in 3D needs to be developed as a single mesh, with no juxtaposed elements. For this monument, laser scanning was held to be the only suitable instrument for the restitution. Both of the studied monuments are of the Byzantine epoch.

3. First case study: The Abbey of S. M. di Cerrate

The Abbey of Santa Maria di Cerrate, situated in open countryside in the municipality of Squinzano, a few kilometres North of Lecce, was founded at the beginning of the 12th century by Norman counts. Its history is similar to that of many other Italo-Greek abbeys of the Salento peninsula. As an important Basilian monastery, which was also the home of a famous scriptorium, the building was extensively modified in the following epochs, a wing with porticos being added to the original structure, along with a sumptuous sixteenth century well and other later additions. Typical of the Salento is the exterior decoration of the church with narrow pilasters and arches, while the rich 13th century portal reflects French tastes. The interior of the basilica was decorated with frescoes between the 13th and 16th centuries, as part of a long and continuous effort to beautify the building, which was a very important centre of religious and cultural life until the 16th century at least. Subsequently the complex was transformed into a *masseria*, a farmhouse, only recently re-emerging as a cultural point of reference for the area; the restoration of the church and of the surrounding buildings included the establishment of an interesting Museum of the Arts and Traditions of the Salento, under the control of the provincial museum.

The interior of the church takes the form of a basilica with three naves, of which the smaller one to the left is connected to the 12th century portico. The façade contains hanging arches that highlight the three-way division, framing two single-pane windows corresponding to the smaller lateral naves and separating the small rose from the richly decorated portal in the centre.

Fig. 3. Santa Maria di Cerrate (Lecce, South Italy), real photo of interiors.

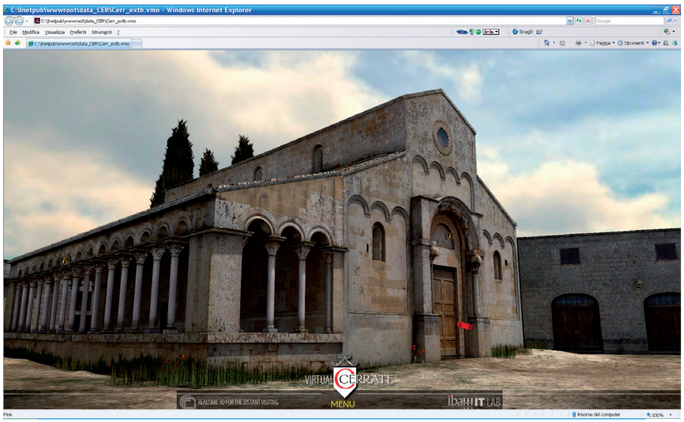

Fig. 4. A screenshot of DVR platform with the navigation interface. Exteriors of S. M. di Cerrate abbey.

The aims of the architectural survey of the Abbey of Santa Maria di Cerrate are to document the current state of the building and construct the three-dimensional models necessary for the development of the knowledge platforms described above. Consequently, the survey operations concerned not only the individual surfaces of the church itself, but also the series of buildings that encircle the Abbey today in a "defensive wall" and form an inseparable part of the same monumental complex. Given this premise, the early phases the work focused on the acquisition of the basic photographic documentation and on the choice of appropriate techniques for the restitution of the monumental complex at a high level of detail and precision. As already mentioned, considering the aims of the communication products and the survey issues specific to this case, it was readily perceived that these requirements could be met by restitution techniques based on digital photogrammetry and photomodelling in particular.

The reasons for this choice obviously include their greater flexibility and ease of use compared to normal photogrammetric techniques, but above all the possibility they provide of obtaining three-dimensional models of great precision at a very low cost (rif. Low cost met, CIPA). In this specific case, it should be stressed that the surveying difficulties resulting from the height of the buildings, together with the problems of accessibility to certain architectural elements (the rose, roofs, upper windows, etc.), mean that considerable effort (and additional costs) would have been required for the deployment of the equipment necessary for a traditional photogrammetric survey. Given the conditions, the adoption of a system based on laser scanning was also excluded a priori, in that this would have required greater processing times in terms of post-editing and would have generated redundant data for the flat surfaces. In an architectural survey with specific aims such as this one, the key factor is the critical judgement of the surveyor, who must identify, by means of a careful analysis of the architectural elements, only the essential points necessary for the restitution. This critical evaluation, which entails the recognition of corresponding points in different photographic shots, is also the fundamental task in photomodelling surveys. In operational terms, it is sufficient to identify the vertices of each architectural element, or insert some targets on the surface being surveyed in the poorly characterised areas, in order to obtain three-dimensional models complete with textures mapped in UVW projection.

The use of commercial software and a simple digital camera for the production of the single basic medium (digital photographs) necessary for the generation of the various contributions (3D models, QTVR) provides a method of reference for small-to-medium operational situations with low budgets. As well as the facility of use and the considerable results that any reasonably skilled operator can achieve in a photomodelling-based survey, this technique, as already mentioned, makes it possible to obtain three-dimensional models with a small number of polygons complete with textures. This characteristic is highly important, if one considers the use of these models as the operational basis for the development of communication products based on 3D metaphors. Every "desktop" solution – and even more so every use on the web – requires models that are optimised for the best management on machines with that kind of hardware.

The task of reconstruction concerned both the outside of the complex and the interior of the church, with particular attention paid to the problem of the

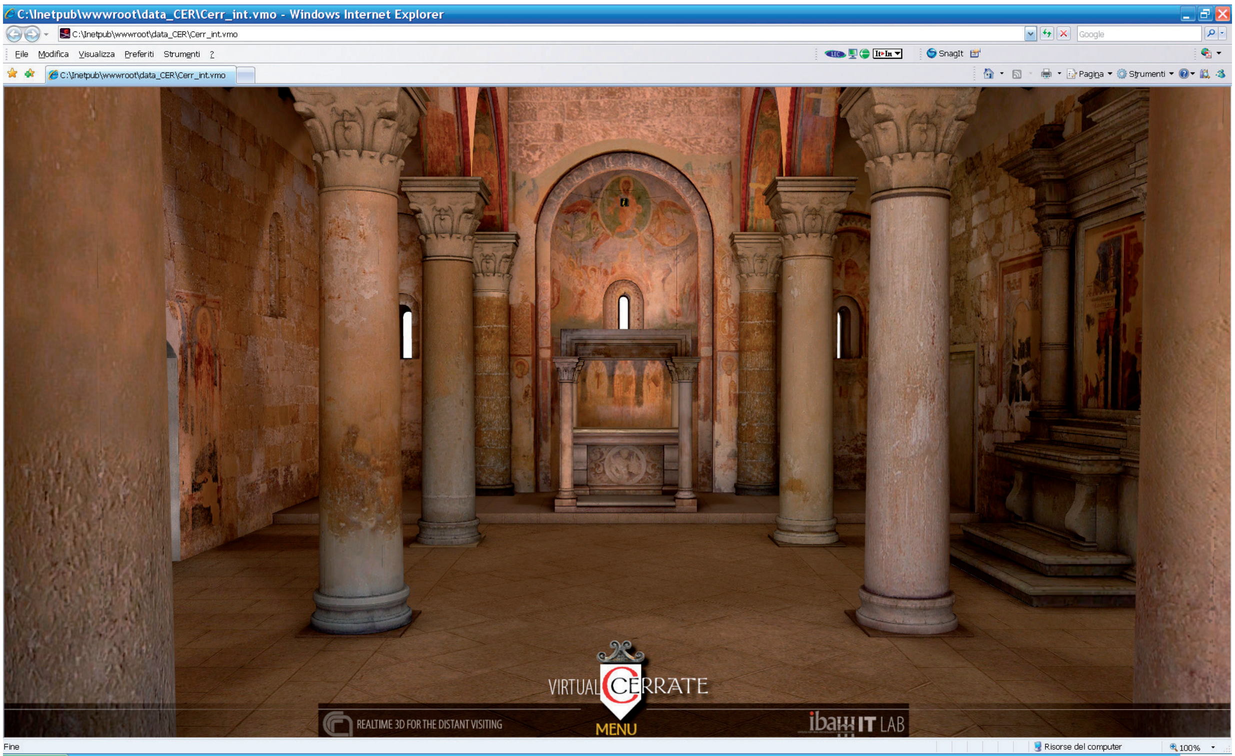

Fig. 5. A screenshot of DVR platform with the navigation interface. Interiors of S. M. di Cerrate abbey.

Virtual Restoration of the frescoes visible today on the walls of the smaller naves. These frescoes are extensively pitted – the result of deliberate damage to the surface to ensure the adherence of a subsequent layer of plaster, which was covered with another cycle of frescoes, and which was removed during restoration. This layer is conserved today and viewable in the rooms of the adjacent museum. By means of virtual archaeology, or rather Virtual Restoration, these painting shave been re-collocated in their original position, above the more ancient frescoes; the user can thus view in a single product the chronology of the historical phases that have been documented and discover in a few minutes the historical evolution of the item over the centuries. Two distinct digital restoration techniques have been developed: the first was used for the re-composition of a fresco of the 13th century on the South wall of the church. As a result of numerous rebuilding episodes that involved the dismantling and subsequent reassembly of the wall, which was painted, in its current state it lacks iconographic consistency, and the reassembly makes this fresco something of a puzzle. Concerning the specific issues involved in the restoration of pictorial cycles, digital restoration is closely linked to all the operations that precede the drawing up of a conservation plan, in accordance with the so-called "guided restoration" approach. This provides a pre-visualisation of the hypothetical restoration measures, but more importantly it makes it possible to restore the legibility and formal unity of the work of art in all its figurative significance, while respecting the principles of modern restoration: distinguishability, reversibility, minimal intervention and compatibility.

The restitution of the fresco entailed firstly a series of photographs using a special support, targeting individual parts of the fresco with the use of photogrammetric techniques. Subsequently, all the parts were digitally re-collocated in a single high definition photograph. The result obtained enabled the partial restitution of the fresco and the creation of a texture that was subsequently applied to the 3D model of the church in its 13th century phase.

Other cases of digital restoration of pictorial cycles involved the re-collocation of two late-medieval frescoes removed during the restoration of the church in 1970. These are today conserved in the adjacent museum. In this case too, high resolution photogrammetric surveys of the paintings were conducted; using archive sources including old photographs and engravings, they were re-collocated in their original position in the new 3D model corresponding to the 19th century phase. The creation of 3D models specific to the individual historic phases of the church gives rise to the concept of "3D digital restoration", understood not as an approach to the ideal reconstruction of an architectural item, but as a method for the verification and the re-composition of analytical data, aimed at the study of the functional and structural logic of a building by means of innovative methods of visualisation. Light simulation techniques based on radiance maps or HDRI, Sub-Polygon Displacement for rendering walls, the generation of filaments for patches of grass, and manually controlled subdivision surfaces for the modelling of complex surfaces (capitals, sculptural elements, etc.), are just some of the many features applied to the reconstructive study of S. M. di Cerrate.

Fig. 6. Virtual restoration proposal of S. M. di Cerrate frescos.

The reconstructive study of a monument today can make productive use of 3D technologies and advanced visualisation systems, achieving results that were unimaginable just a few years ago. Studying a monument in every detail, visualising forms and colours in three dimensions, is now an indispensable support for researchers, but the computer and advanced technologies are only the means, and in no case can they ever become the ends of the research. Thanks to technology, the case study proposed here makes it possible to open a window on our past, but the true objective is and remains historical and archaeological research, which thanks to Virtual Reality can be narrated and represented as never before.

4. Second case study: The rupestrian church of Madonna delle Croci

Entrance to the crypt is through a round arch with a simple rectangular door in the centre of a semicircular façade carved in the rock which contains a series of niches and engraved crosses. The interior, rectangular in shape and oriented East-West, is subdivided into two vaults separated by a segmental diaphragm arch. Each vault is supported at the sides by blind arches where, in the vault closest to the entrance, numerous crosses are engraved. The name of the crypt derives from the presence of crosses engraved on the walls and three large crosses on the vaulted ceilings. In the vault closest to the entrance are two crosses in relief, both set in the centre of a circular cavity, the first of which is of the "pattée" type and the second of the "potent" type. In the inner section of the church, the ceiling is of the groin vault type, and between the arrises on the side of the apse is a third large cross inscribed in a circle, also of the "potent" type.

Fig. 8. A real photo of Madonna delle Croci, Matera.

Fig. 7. Axonometric view of S. M. di Cerrate abbey.

Figs 9–10. 3D restitution from laser scanning and Camera mapping of Madonna delle Croci church (Matera, Italy).

Of the original pictorial decoration only the fresco on the apsidal vault remains. Dated to between the 12th and 13th centuries, the fresco reflects the typical Byzantine-style iconography of the enthroned Madonna and child flanked by two archangels, Gabriel and Raphael. The survey of the internal walls of the crypt was performed with a time-of-flight laser scanner. The acquisition was based on domes of about six metres in radius, with a level of detail of the point clouds of 2–4mm. Five scans were necessary, three inside and two outside, to describe the entire item with a good coverage of the undercuts. The scanner proved to be fast and reliable, but the editing of the point clouds required a considerable effort on the part of the operator to resolve problems caused by exporting in the dxf format, which resulted in pronounced anomalies and discontinuities in horizontal bands at regular intervals. In each case the manipulation of the meshes using software dedicated to the management of point clouds resolved the problem satisfactorily, and the results are visible in the images shown in this article. The polygonal mesh was subsequently decimated in order to maintain the number of polygons within a limit that was empirically tested on normal consumer computers, in the order of 400–500 thousand polygons. In the texturing phase, this limit, imposed for reasons linked to the performance of the RealTime engine, considerably simplified the selection of the groups of faces to which each individual material was assigned. The internal walls were mapped using the Camera Mapping method, well-known and used in cinematography, but rarely used in other applications such as the restitution of monuments. Our experience has shown the excellent performance of CM on curved surfaces, for example the apsidal wall or the underside of the arches of the lateral walls; on all the other surfaces an extensively subdivided planar projection was used, again to limit distortions in the undercuts as much as possible.

The hyper-realistic result clearly derives from the skilled fusion of the individual polygonal "sectors" mapped using these techniques, but another element that contributes to the photorealism is the choice of illumination, which must be as close as possible to the natural illumination resulting from the original photographs, obtained using a 12 Megapixel camera in RAW format. The choice of illumination was based on the Radiosity-type algorithm, using HDRI (High Dynamic Range Image) images and area light from the church's only opening. The artificial light merely helped to accentuate the atmosphere of a closed and dark space, stressing the light-dark contrasts, also accentuated by the closed nature of the environment. The final model of the entire complex is made up of about 300,000 polygons with two textures re-sampled at 7000 x 7000 pixels. The RealTime navigation is easily managed on a normal consumer PC, with non-professional hardware and software configurations. The level of verisimilitude can be judged from the images shown here.

Conclusions

The creation of a virtual navigation platform in RealTime implies the use of three-dimensional models with a low number of polygons in order to guarantee an optimal user experience with reasonable response times. The speed of the system is the indispensable condition for the emotional involvement of the user in a virtual context. The process of simplification and decimation of the data entails a loss of information, which is most important when the object being modelled is a fundamental part of a scientific or teaching process involving the transmission of historical and artistic information. The results visible in these pages derive from a measured equilibrium between the level of modelling and the realism of the textures, which compensate for the deficit in micro-geometric detail.

The aim of this work remains however essentially communicative and museum-oriented, since it will prove useful and effective only if it transmits to the final user the greatest amount of information possible. This includes "highlighting" aspects of interest that might be missed by the inexpert user, using suitable methods and communication tools that are also appropriate for the various possible levels of interest and comprehension.

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