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Bringing Impossible Places to the Public: Three Ideas for Rupestrian Churches in Goreme, Kapadokya Utilizing a Digital Survey, 3D Printing, and Augmented Reality

Abstract: The churches of St. Eustache, the Meryemana and St. Daniel are located in the Göreme area in Kapadokya, Turkey. Each of the three structures is composed of a main church with a refuge system. Nowadays these churches have limited access: they cannot be visited by a common tourist. Thus, they are a meaningful sample of rupestrian architecture, containing important mural paintings and suggestive spaces. Using digital survey techniques, 3D modelling and 3D printing to produce physical copies from the originals, this research project tries to find articulate and well working solutions to bring these architectural structures to the public.

Keywords: Kapadokya, Turkey, 3D Laser Scanner, Rupestrian, Churches

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1 Introduction

Kapadokya, in Turkey, is a well known area for its peculiar artistic and naturalistic environment. Lately it has become a major tourist destination, experiencing significant changes in a similar manner to the local economy, which in the past was primarily agricultural. Kapadokya's rupestrian landscape shows an incredible vision of a rich and unique geological environment, which recalls, in the shapes of its erosion, evocative perspectives and architectural or fantastic visions. It is a land heritage made of rocks, gorges, valleys and headlands, enriched by ancient populations with an intense work dedicated to the creation of cavities used for residences, depots, farming and religion purposes. This vast heritage, as well as the material that constitutes it, is fated to a slow and progressive degradation. Sometimes this process is accelerated by the presence of the same voids created by the rupestrian settlements: parts of rock collapse and bring to the sunlight entire sections of underground cities; the internal wall of a church becomes its façade; the core of a peak can reveal portals or apses. In this complex situation, it can be difficult or unsafe to visit and access these places carved in these slowly decaying stones of volcanic origin. In this situation the architectonic research often has to face the issue of producing effective documentation and ensuring an appropriate access to these structures. At the same time, the *in situ* maintenance interventions on these stone architectures often risk damaging the original qualities of the places, and tend to sacrifice the "poetry" of the site in favour of tourist access; while in some other cases involving collapse or hazard, it

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is impossible to create a safe access to spaces that are very difficult to repair because of their current fragile state (large cracks, elements close to falling, risky passages, etc...).

In this area, the interventions for consolidation, site safety and for granting the access clearly appear as strong deviations from the original conditions. In most cases, the conservation of painted interiors is prioritized, while the intervention on the exteriors alters the original features. Metal ladders, scaffolding, coatings, and structures made of stone or concrete blocks can slow down the process of erosion, contain collapses and ease the visitors access. At the same time, however, they deprive the spaces of their specific original features, clearly showing the limitations of a "traditional" and direct approach to the restoration of these types of Cultural Heritage elements.

It seems that there is a dual issue to deal with: the need to preserve the rupestrian structure, slowing its consumption as much as possible and postponing the risk of its collapse; and the problem of how to realize its diffusion and fruition while keeping reasonably intact the appearance of places, together with their "poetics of ruin", accordingly with the values expressed in the romantic form of the poem *Ozymandias* by Percy B. Shelley, instead of in the *Patissier pittoresque* by Marie-Antoine Carême [3].

The issue of a proper and intelligent restoration is certainly essential, but at least the approach to the intervention on the wall paintings seems to have been initiated by the Turkish authorities. This is a vital process that acknowledges the integration of different experiences involving know-how from other countries as an important step to define the correct methods in such a delicate scenario [4]. There are many things that still need to be done to improve the outcome of the "architectural" restoration, which currently seems to highlight the limits more than the protective aspects of the results. Both of these conditions can be directly observed in the *Tokali Kilise* in Göreme, where the high quality of the restoration obtained for the wall paintings, conducted by a team of Italian and Turkish restorers, contrasts with the massive consolidation of the exteriors.

The digital technologies of our time create an interesting and innovative condition, integrating a further path to the documentation, visualization, dissemination and visitation of these monuments. Such a condition was formerly impossible, but now sets a very interesting challenge of developing exhibit solutions starting from the data produced during the documentation phase in order to create a significant and context-sensitive opportunity. In this way, visiting the "digital" version of the monument is not necessarily a reductive moment or a compromise compared to the real visit.

The churches of St. Eustache, the Meryemana and St. Daniel immediately appeared as perfect examples and case studies for this research: they are located outside the main area of the Open Air Museum in Göreme, largely well preserved in their main rooms and possessing different degrees of inaccessibility and low usability among the churches in this area. For the St. Daniel church the main limitation is to belong to a group of rocky peaks containing some places of worship and a convent, a specific system of refuges, and two churches: one dedicated to St. Daniel, with still intact wall paintings; the second church, non-iconic, typically decorated with geometric red patterns. The degradation and the fragility of the paintings in the first church (hence it is perpetually closed) and the fragmentary nature of the space make it difficult to read the complex which is still arranged in three levels along the peaks. The Church of St. Eustache, enhanced by a beautiful and richly painted barrel vault, currently has its entrance about four metres higher than the ground level reached by the access trail. The only way to enter the church is to use a ladder, since a permanent staircase would compromise the appearance of its collapsed façade, limiting the visibility of the refuges all around and interrupting (only partially) the visual relationship with the Uchisar Castle, located a few kilometres away, but clearly visible from the openings of the refuges and from the church itself.

The last and most dramatic case is the Meryemana, which displays the most striking examples of degradation that are common to this type of architecture. It is a rupestrian church of great beauty, used as one of the set locations for the movie "Medea" by Pier Paolo Pasolini in 1969 [5]. The place has always been difficult to reach because of the few entrance passages, but now it is permanently closed to the public because of the impending threat of collapse. Richly shaped and decorated, the "House of Mary" is afflicted by a large crack that divides the whole church into two parts, allowing water to percolate down on the wall paintings. It is threatened by the final collapse of the 17-metre peak above the church into the hollow of the valley 25 metres below.

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2 The Digital Survey

The initial phase of the documentation process for these cave churches and their surrounding environment was based on a careful and accurate digital survey. For a subject like this rupestrian area it was quite clear that there would be the need for multiple tools, but all would be organized around the use of a 3D laser scanner unit.

The three churches have been measured and documented during two campaigns operated in 2012 (St. Eustache, interiors of the Meryemana) and 2013 (exteriors of the Meryemana, St. Daniel). The whole set of data used in the subsequent processing comes from these two campaigns. The 3D laser scanner used in all of these stages was a phase-shift type, a Cam/2 Faro Focus 3D. This unit offers good accuracy combined with easy handling, small size, low weight and a compact tripod. The working range of this instrument ranges from 0,6 to 120 metres. It turned out to be the ideal tool for the operations carried out, creating easier conditions by allowing scans inside narrow tunnels and cramped stations. The positioning of the scan stations was decided according to the shape and to the specific conditions of each space. The surveys were completed taking numerous scan stations, all of them operated in full panoramic mode, and exploiting the characteristics of the 3D laser scanner in use, which was capable of scanning 360° on the vertical axis and 320° on the horizontal one. For St. Eustache, a series of 114 scans were taken to cover the structure of spaces, the refuges and the exterior parts. A set of 15 scans were enough to cover the interior of the church. For St. Daniel (fig. 1), the number of scans was 80, with a set of 16 for the interior of the main church. A set of 10 scans was used to document the aniconic church. The scans taken in 2012 for the Meryemana were 36 (fig. 2), and another 32 were taken in 2013 for the completion of the exteriors.

Figure 1: The complex of St. Daniel Church, point cloud view (F. Rafanelli).

A part of the scans were taken using the photo shoot function of this scanner. In order to have good mapping quality from the painted surfaces, a specific photographic campaign was done for each subject. The photographic documentation (both for general use, texturing and also for photogrammetry) was taken using a Nikon D700 12.3Mp (St. Eustache, Meryemana, 2012) and a D800 36.3Mp (St. Daniel, 2013). For the specific case of the Church of Meryemana the shooting of full sphere panoramas was also carried out. These specific sets of images subsequently proved to be a particularly practical implementation for texturing the three-dimensional models derived from the point cloud. The panorama shooting was made using a Pentax K7 15Mp camera with a standard 18-55mm zoom lens. Moreover, when it is mounted on a tripod with a specific panorama head, the camera is able to rotate around its nodal point to reduce parallax distortion. Each single panorama was made from 60 pictures. All the laser scans have been planned in such a way as to minimize the occlusion spaces produced from the complex shapes of the rupestrian architecture. At

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Figure 2: The Scanning at work inside the Meryemana.

the same time, there was the attempt to avoid the over-measuring of surfaces. This was done by trying as much as possible to have valid margins of overlap between each scan. At the same time, the density of each point cloud was always balanced with the real needs of documentation, which means, first of all, keeping a resolution similar to the accuracy allowed by the scanner. For this reason, using a 3D laser scanner unit with a ranging noise of ±2 millimetres, the planned work was aimed to have an aligned result with an average sampling of 2 to 3 millimetres for the interiors and 5 to 10 millimetres for the external surfaces. The final result, though very demanding in terms of the total collected data volume, is a balanced and viable dataset that is capable of being moved to the subsequent data treatment, but without the need to involve heavy simplification of what has been collected. For example, the point cloud of all the interiors of the Meryemana Church was made by 61 million points. Particular interest was paid to the possibility of bringing together the scans of the exterior parts with those of the interiors, producing a very detailed and comprehensive reading of the relationship between shape, architectural features and organizational features, combined with the status of the erosion or of the collapse. The survey operations for all these churches were carried out in an almost equivalent period of time, except for the Meryemana, which was surveyed during two separate campaigns, the first in 2012 and the second in 2013. In detail, the data gathering of the Meryemana was organized in the following way [1]: during the first campaign the survey took care to document all the interior spaces and the access passage leading to the church starting from the ridge, passing through some very tight openings and alternating between still recognizable rooms and spaces now completely opened by the consumption of the stone. During the survey campaign in 2013 the scanning of most of the surfaces was completed: of its hosting peak and of all the exteriors from the ridge to the bottom part of the valley.

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The presence of a large crack with a visible detachment ongoing and the threat of a possible collapse create a meaningful condition of risk for any visitors of the church. To better document the state of this damage, an additional set of stations was dedicated to surveying the system for cracks. In order to do this, the laser scanner unit was placed along the crack and centred on its axis, so that it was possible to have the laser beam capturing the two sides of the crack at a certain depth. After the first inspection in the 2012 survey campaign, it was immediately clear that it was necessary to document the Meryemana as soon as possible because of the worsening of the crack. The decision to take an immediate survey of this church with all the interior parts and of the nearby passages turned out to be a good choice, since in the following year the local authorities permanently forbid access to this church because of its dangerous conditions. However, in 2013, it was possible to complete the survey of the exterior elements using morphologically recognizable elements and then using them as targets in the neighbourhood area. This was done by simply taking the scans of some overlapping areas with surfaces common to the survey taken in 2012.

The rock material of the whole area turned out to be able to reflect the signal of the laser effectively, responding well to the phase variation measurement operated by the scanner and also making the gathering points easy from the maximum operative distance. Even at the longer operating distances provided by this tool, the points were taken with good density also in the range around one hundred meters without the need for high redundancy or density. Despite the common good quality of the long distance points, it was decided not to use these points directly as references for the alignments, but to use the points closer to the scanner. These areas have proved to be clearly legible without causing any mismatch phenomena, making it possible to produce the vision of an organic and detailed space from the aligned point cloud, a model able to describe accurately a picturesque landscape that is otherwise afflicted by a difficult geometric representation. Although the stone surface has responded well to the signal of the laser, the application of planar targets, which are commonly used on manmade architectural structures, has proved to be difficult. This is because the soft shapes and the organic surfaces of the stone are brittle and have a sandy layer. These features, together with the environmental conditions (the wind wedged in the spaces, temperature changes between day and night and sometimes a high level of humidity) have made it preferable to avoid applying temporary targets fixed on the walls or in the area nearby. There were too many problems for the stability of the targets. The implementation of some mobile targets and the recognition of morphologic elements (spots, cracks, signs, small stones, etc...) for the following alignment of the scans were preferable options. For this reason, it was preferable to maintain a certain degree of overlap between each single station and to position the scanner in the conditions where it was capable of facilitating the recognition of common elements from one scan to the next.

3 The Treatment of the Data and Modelling

After the end of the survey campaigns, each dataset of the churches of St. Eustache, St. Daniel and Meryemana was immediately processed from single scans to form a complete, aligned point cloud. This procedure has created specific archives with the three-dimensional descriptions of each architectural structure. Later, the surveys of single structures were going to be combined in an overall model of the rupestrian settlements of this area.

The main software tools used for the first alignment of the data were Cam/2 Faro Scene and Leica Geosystems Cyclone. The registering process was based on the target system (where available) and/or on the basis of morphologically recognizable features. This increased the overall time of alignment, due to operations that have always required a lot of precision from the operators in order to prevent small errors from progressively reducing the level of accuracy.

Therefore, the three groups of scans have been processed for the development of a comprehensive model based on the point clouds that are well descriptive of all the interiors and exteriors of the three churches. The point clouds were available in variable densities, the denser for the interior (with points on a grid spaced between two and four millimetres apart) and the sparser for the outer surfaces (with points spaced generally between five and ten millimetres apart).

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The resulting occluded spaces appeared minimal and not significant for all the internal scans, while some parts of the exterior presented some appreciable holes. This was due to the inaccessibility of some areas and the presence of some large elements opposed to the viewpoint of the station. However, the occlusions in the external surfaces were not an impediment to the legibility and completeness of the collected data. The dataset quickly became a valuable starting point for further treatment.

Once the first phase of restitution was completed, with the alignment of the individual churches done, the extraction process of the two-dimensional drawings was started immediately, which is oriented towards the production of traditional representations that are useful for reading and understanding each structure. The definition of plan view, elevations, and sections allows a rapid interpretation of the articulate complex, especially in relation to the system and the morphology of the territory in which the church-convent-refuges system is located (fig. 3 and fig. 4).

It is important to keep in mind that what we have seen today has been significantly changed by erosion and collapses, and the product of this consumption is largely deposited at the feet of the settlements,

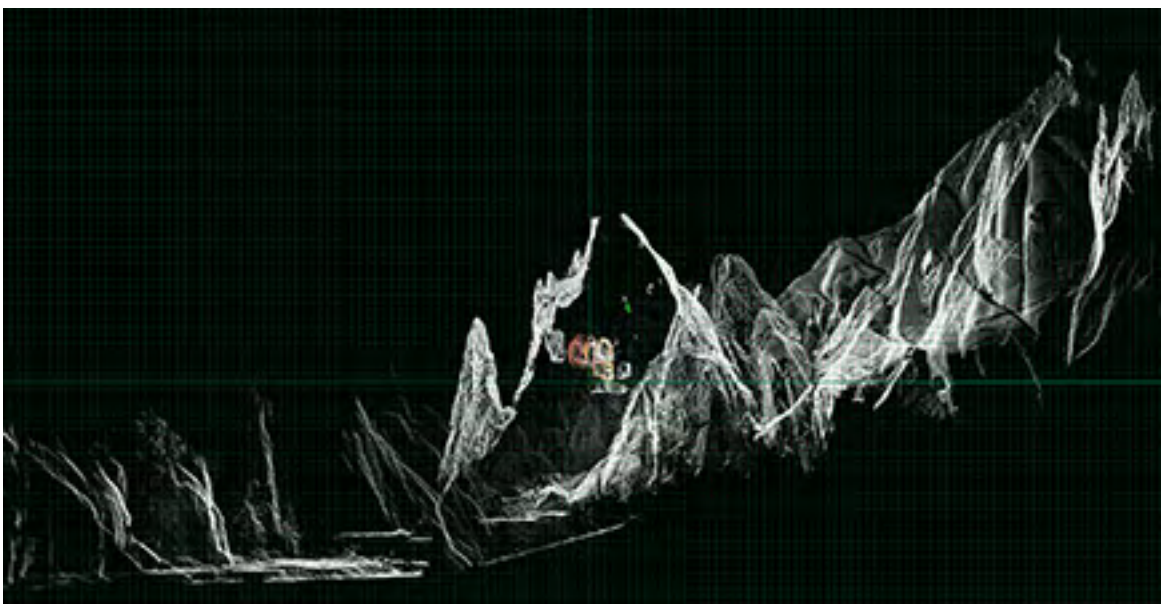

Figure 3: Cross section passing by the Meryemana Church, point cloud view.

Figure 4: Cross section of St. Daniel Church with some of the refuges (F. Rafanelli).

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resulting in significant burial of the lower floors. However, the readability of the relationship between the compartments and the structuring logic of many areas is still clearly understandable and it is an interesting subject that can tell a story and help archaeologists know these places better.

Creating plans and sections is often a useful phase of this interpretation, highlighting the dimensional relationship and alignment between excavated spaces, even when they are located at a significant distance one from the other. At the same time, these drawings can propose an architectural image of the settlements that can be very effective both for research and for presentation to a general audience, using a well coded language (fig. 5 and fig. 6). The use of the traditional solution of representation can exploit the deep rooted language of drawing to better tell the story about the structure of these places. The following processing has led to the passage from the point cloud representation to the one based on polygonal surfaces. In this way, the model is closer to the common perception of reality, losing the characteristic "transparency" of the original points.

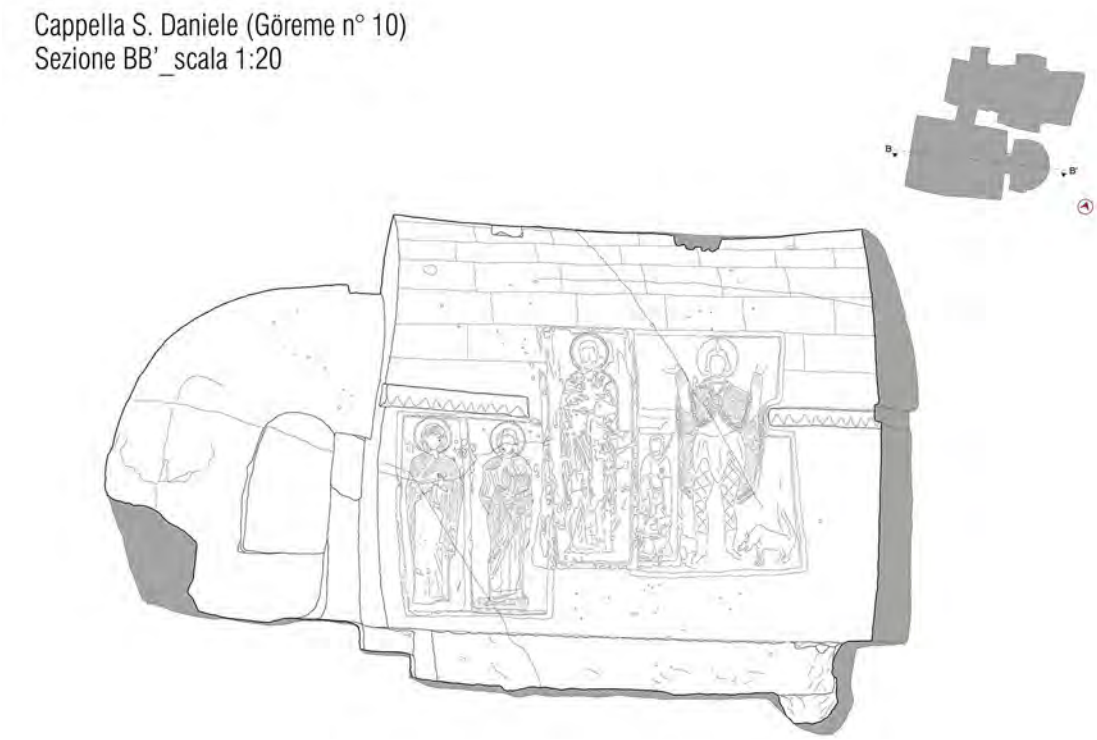

Figure 5: Cross section of St. Daniel Church, main chapel (F. Rafanelli).

Figure 6: Plan view of the Meryemana Church (C. Gira).

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The second necessary step is the need to optimize and close the remaining gaps in the surfaces. The purpose of this process is to reduce the number of polygonal elements in order to supply the model with a minimal number of faces that are suitable to describe the object with a correct amount of details relative to its use (multimedia, analysis, representation, archiving). The main adopted solutions generate a mesh surface free from "holes".

After the completion of this very detailed model with a high number of polygons, it was time for the generation of a lighter and more manageable model, optimized and aimed to fulfil the functions for which it was intended (displaying in real-time, creating rendered images, creating animated rendered sequences, modelling for 3D printing, modelling for design and presentation purposes). The starting surface model (the one with a high level of detail) was also used again in order to extract its specific normal map, designed to bring the level of detail of the original model to the simplified model [12,14], but without increasing its complexity and "weight" in terms of hardware requirements for browsing and downloading it (fig. 7).

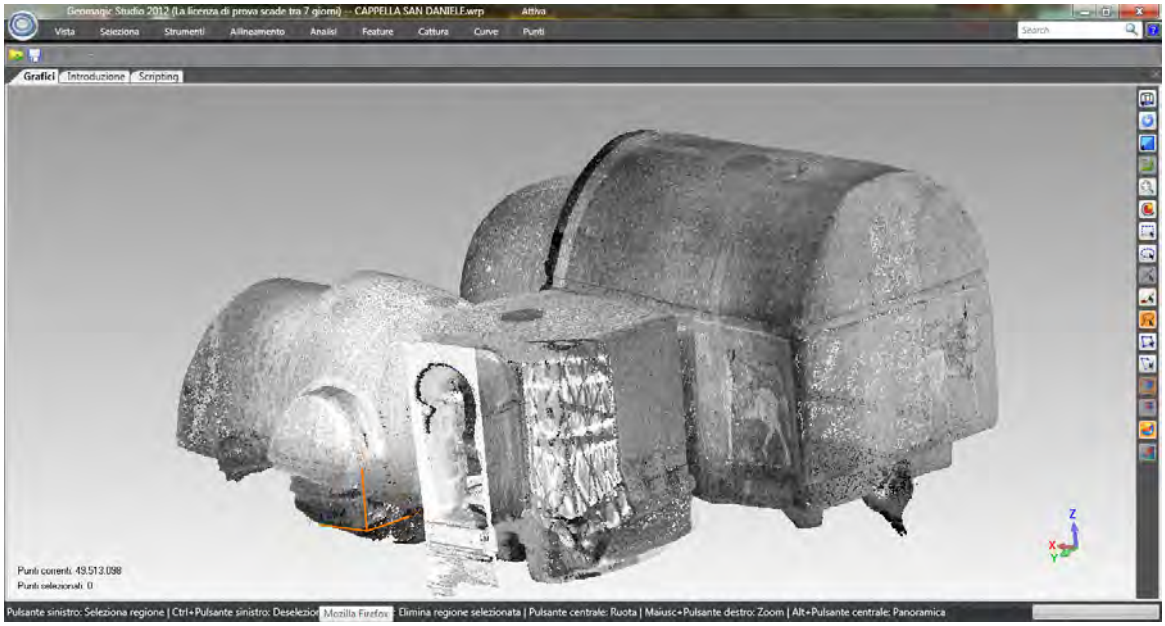

Figure 7: Editing the St. Eustache model in Raindrop Geomagic (V. Niccolini).

Adopting a typical solution widely used in computer graphics for video games and cinematography turned out to be a good approach for these rupestrian elements. In one example from the point cloud of the interiors of the Meryemana (61 million points), the first mesh generated was made by 37 million faces. From this "heavy" surface a first reduction treatment produced a mesh comprised of 6,8 million faces, while a further treatment created a "light-weight" version made of only 570.000 polygons. For the case of the Meryemana Church, the software used for the simplification process was Pixologic Zbrush, exploited for its retopology functions. For the other churches, the mesh treatment was completely operated using Raindrop Geomagic Studio. The process of texture making was done using specific pictures of the main churches and differencing the texturing of generic parts with the one for the mural paintings (fig. 8). The completion of the texturing was performed using different solutions depending on the church and the purpose of the model, but for the most part the classic processes of association between the image point and the vertex on the surface have been used. For some models it the solution of direct reprojection using "virtual" cameras was preferred. The main software tools used in this step were Raindrop Geomagic Studio, Pixologic Zbrush, Autodesk 3D Studio Max and Maxon Cinema 4D.

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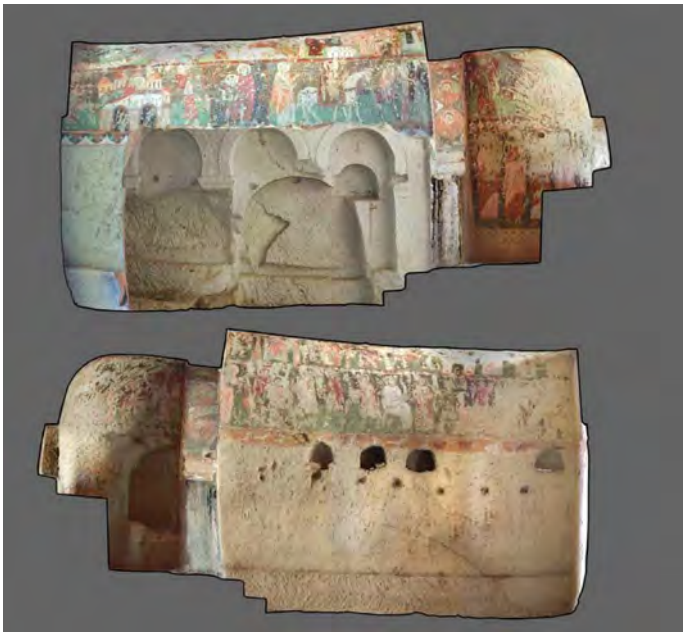

Figure 8: Cross sections of St. Eustache Church (V. Niccolini).

4 The Design of the Museum

When the digital models were finalised two issues appeared. The first entailed proposing a solution to present them to the public: how the process of virtual visiting these artistically and historically significant places could work using a solution relying on the digital database without necessarily "dematerializing" the perception of the Heritage site itself. The second concerned the solution about how to keep the digital model connected to its original places. This kind of approach has already been experienced in the past, in some cases aimed at the preservation of monuments from tourism pressure, such as the caves with paintings of Altamira, in Santander, Spain [13]. The first clone of this space was made by Manuel Franquelo and Sven Nebel in 2001, and it was followed by additional copies in museums placed in other parts of the world. The idea of a physical copy for the rupestrian churches guided the reasoning since the early stage of the project. Creating these copies would inevitably cause a partial "loss" of the quality of the original, although technologically advanced solutions can produce an enhancement and offer significant added values [7] based on advanced, but not intrusive, digital solutions: a technological clone, non-invasive and able to convey specific information. In this way, the visitors can obtain knowledge of these environments in their original shape but with some meaningful enhancement, a solution that can perhaps bring these ancient structures, nearly a thousand years after their realization, into the age of the information revolution.

A process with three distinct levels has been defined in order to create the ideal conditions for testing and optimizing each church, with the intent to suggest solutions in an episodic way. At the same time these solutions will be able to interact each other and to offer a visit to the "special" in each church according to its characteristics.

Then the following types of development were defined: in each of the three levels of the solution the exhibition space for the church is being considered as an architectural subject, a small pavilion with fully reversible construction in respect to the environment that can be installed, operated and removed without leaving a trace. Individual functions are offered, but coordinated with other displayed units that are suitable to be positioned close to the original church, but also suitable to be transported and reassembled elsewhere for taking the specific exhibition to other places and spreading the knowledge of these magnificent artefacts. Specifically, the three proposals were formulated as follows:

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Level 1 - traditional digital models, traditional physical models - is the solution prepared for St. Daniel. The starting considerations are: it is a double church and a monastery within a system of well-distinguishable peaks, so the apparatus of the mural paintings is very well circumscribed and can be easily "separated" from the shape of the hosting peak; the main church is not easily accessible because of the number of burials in the entrance compartment; the space of the monastery is not easily accessible without the use of ladders and requires some slightly acrobatic passages, often through partially buried spaces or pit passages.

In this case the proposed solution has provided a traditional layout based on explanatory panels and scaled three-dimensional models. All the component parts of the panels were made from data derived from the 3D laser scanner survey or photographic materials produced during the survey campaigns. The models on display are designed as models offered to the public with solutions of direct contact, so that the visitors can touch and move them in order observe them from different points of view. The ability to replicate models and their realization in synthetic materials such as PLA (polylactic acid, a thermoplastic used in 3D printers) suggests how these models are capable of supporting even long periods of exposure to the public without suffering significant damages, eventually to be replaced at the appropriate time for a low cost. In this way, the understanding of the shapes and the articulation of the system formed by the churches and the refuges can be reached in a very direct way, where the scaled representation allows visitors to understand more clearly the actual structure of the complex and the relationship between parts. The set of explanatory and descriptive panels allows for complete understanding of the structure, adding detailed information about the wall paintings, the articulation of functions, the original use of the complex and the hypothesis about its development and its characteristics relative to its original environment.

Level 2 - physical models integrated with digital models - is the solution defined for the Meryemana (fig. 9). The initial considerations were: the building is inaccessible because of the collapse hazard in progress; potentially it is a structure intended to be irretrievably lost; it presents a set of wall paintings very complex and closely linked to the shape of the spaces; the architectural aspect of the church is a significant vision, but it is an architecture that can fully impress even from only a few points of view; the context and the drama of the impending collapse greatly increase its power of suggestion.

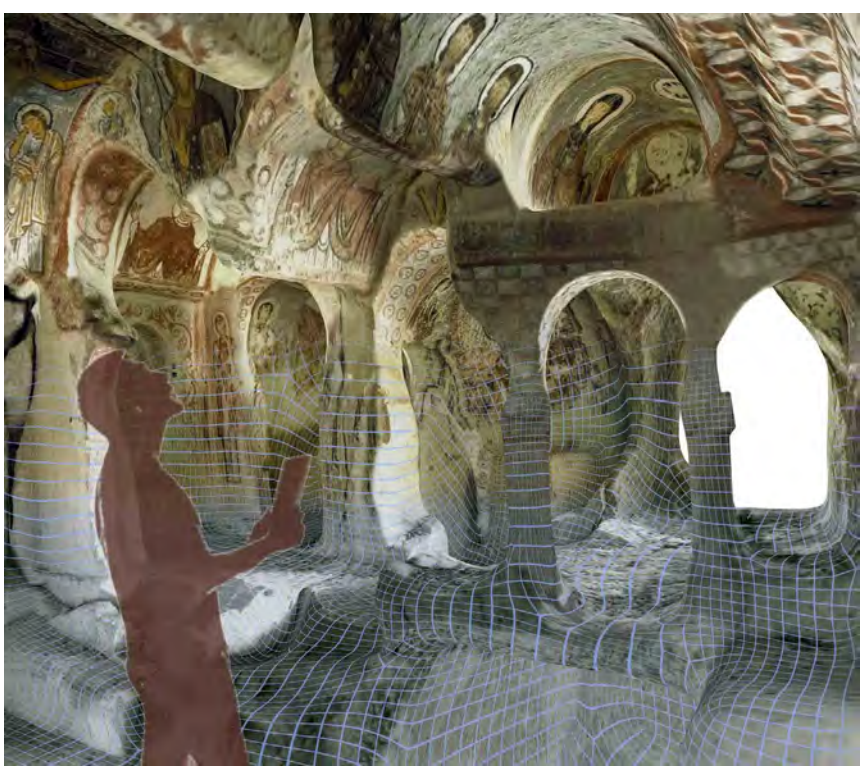

Figure 9: The concept behind the Meryemana augmented reality exhibition (C. Gira).

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In this case the proposed solution is based on a model made with the 3D printing process, scaled or even reproduced to the true scale (in part or in its entirety), but for which the entire apparatus of the wall paintings is displayed over the physical model by an augmented reality system. In this way, regardless of the scale determined by the representation of the model, it can manifest the whole texture so it will be possible to view it in a realistic way directly from a personal device, such as a tablet or a smartphone, without the need of complex and unique immersive systems as long as it has the ability to connect to the Internet (possibly via a wifi network available at the installation). An important factor of this solution is to allow the display of a three-dimensional model actually amplified in a reduced scale, or even 1:1. The connection system between real and virtual is based on a simple QR code that can be acquired directly from the device of the visitor.

The ability to incorporate themes and versatile versions of the model with augmented reality makes it particularly effective and attractive for any fan of the Cultural Heritage and technologies, creating an effective experience in the best tradition of the Digital Heritage.

Level 3 - the physical model, cloned, becomes an alternative to the reality. This solution has been defined for St. Eustache. The initial considerations were: the main church is very simple, as the whole apparatus of the wall paintings is focused on a single barrel-vaulted space; there are no access solutions from the ground (the entrance door is four metres over the terrain). Placing a staircase is something to avoid or it will compromise the front towards the valley.

In this case, the solution consists of a layout based on a real scale clone model of the rock church, made without looking for the exact reproduction but instead by adopting a “clean” space with great detail from the artefact which can be visited as a technological clone. The main part of the room is turned to allow a solution for rear projection with a specially studied and designed digital beamer. The creation of the barrel vault is made using a minimum thickness of resin material in a sintering 3D printer. This solution will produce a set of elements divided into portions and reinforced with thicker elements according to the subdivision of the mural painting itself. The minimal thickness makes it possible to have a transparency allowing an effective multimedia presentation, which offers a vision of the current state of the entire mural painting and its specific versions: one with the painting reproduced in a simulation of restoration and free from chipping, fading and damage; and a “talking version” describing the various figures in the painting (fig. 10). The model, as an experiment, has not been carried out in its entirety, but a small portion of about 25x40 centimetres was built, with the same thickness expected for the full version, and it has been tested with video projections. The resulting effect was very gratifying and showed how through a video mapping solution it is possible to realize a clone capable of restoring a different visiting experience for an object that can be valuable and is also better understandable by its visitors. The entire construction of St. Eustache was studied in a shape that can be dismantled and composed from a certain number of blocks and can be easily assembled and reinforced by a steel frame. The entire display system was designed as removable and transportable within just two containers of standard size.

Figure 10: Cross section of the physical clone of St. Eustache (V. Niccolini).

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5 Conclusions

Digitization of Cultural Heritage is an advanced form of copying from the original. It has extreme potential, but it requires reasoning and understanding of the processes. Often the very fast development of digital systems may provoke astonishment and distract from the ultimate purpose and highlights, especially the appearance of new or particularly successful solutions compared to the real value of the object. But the key object of the process is the Cultural Heritage. Any digital model, any copy will be nothing but a reproduction of the original. All the other replicas will appears like simple compromises; they will have very nice mimicked features in look and appearance, but interesting and useful copies will still be secondary if compared to the magnificence and the presence of the authentic structure.

However, the "wonders" of our technological era offer a great opportunity and, at the same time, present a great challenge to create models that do not strive to simply mimic the original. They can use the same language in different forms, relying on specific and immediate forms of presentation and the dissemination of appropriate technologies, so that they can inspire the visitor's desire to see the original, but at the same time allow him or her to experience these copies as an opportunity to better learn and better understand the characteristics of the original itself.

The research presented here, while remaining for now a project and not having been realized except for the simple experimental or virtual parts of it, has illustrated the concept of this approach. This concept has found an application in the rock churches in Kapadokya, a rich cultural environment capable of contributing to a better understanding of some of the potential of the relationship between Cultural Heritage and Digital Techniques of representation and presentation.

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