# Digital Layered Models of Architecture and Mural Paintings over Time

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**Abstract**

*The European project Enhancement of Heritage Experiences: The Middle Ages. Digital Layered Models of Architecture and Mural Paintings over Time (EHEM) aims to obtain virtual reconstructions of medieval artistic heritage -architecture with mural paintings- that are as close as possible to the original at different times, incorporating historical-artistic knowledge and the diachronic perspective of heritage. The project has also the purpose of incorporating not only how these painted buildings are and how they were, but also what function they had, how they were used and how they were perceived by the different users. EHEM will offer an instrument for researchers, restorers and heritage curators and will "humanize" the heritage proposing to the spectator of the 21st century an experience close to the users of the Middle Ages.*

## 1. Introduction

The academic study of colour in medieval architecture initiates in nineteenth-century France. Medieval painting was frequently whitewashed or hidden under layers of lime, behind liturgical furniture or altarpieces, whose original belonging to their architectural sorrounding is altoghether problematic. In the Middle Ages, mural painting was architecture's epidermis. This debate gave rise to an interest in the building's original makeup, and the paintings that remained in sight were gradually catalogued, as well as those that, as a result of these restorations, were discovered under modern plastering. This at first was the catalyst towards the rapid degradation of what was exposed. At the same time, its discovery generated the interest of merchants and collectors who with extraction procedures, generally strappo, purchased fragments of these decorations ultimately causing their dispersion. Thus several churches were "dispossessed" of their "skin"; the paintings moved to new supports, geometrically regularized, for exhibition.

During the Middle Ages, both architecture and paintings changed over time, and should be understood in their new forms. In some instances, it is possible to identify successive stages of transformation pertaining to the building after the medieval painterly cycle was completed. In others, successive decorative campaigns were carried out resulting in the overlap of previous paintings or completing other parts of the building. In all cases, whether they were left in situ or ripped, paintings were restored with different and changing criteria, according to their own historical momentum. Dispersions, restorations, changes in conservation conditions, destruction by natural phenomena or due to war, have produced and continue to produce losses and modifications of Europe's cultural heritage. If we fail to act to prevent these causes we may lose, and in some cases we have already lost, essential information to understand heritage today and in the future.

## 2. State of the Art

The study, representation, presentation and restoration of the Cultural Heritage (CH) of the Middle Ages has tended to focus on a particular historical moment, the one considered most brilliant or relevant, forgetting previous moments and subsequent changes. The application of digital technologies to cultural heritage has contributed to its wide dissemination, with open access projects such as EUROPEANA, Google Arts and Cultures and CyArk. A number of EU projects have also highly contributed to advance in this direction, e.g. PARTHENOS, Scan4Reco, INCEPTION. The latter, similarly to EHEM, deals with the evolution of CH but it is exclusively centred on the geometry evolution whereas EHEM addresses all the components, including wall paintings. A third family of ICT tools are platforms for publishing and sharing 3D models like 3DHOP or Sketchfab. In most cases, the trend is representing heritage in a single moment, which most often is the present.

## 3. Objectives

For understanding, promoting and revealing a site that preserved or contained mural painting, we have proceeded to show it from its high point. This simplification causes the alteration of the process of changes and adaptations that constitutes the rich biography of the building and its decoration. The exhaustive documentation of these
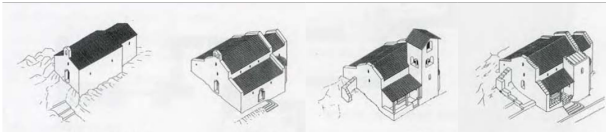
**Figure 1:** *Sant Quirze de Pedret cent. IX, X, XIII and 1995. Source: Diputació de Barcelona. Servei de Patrimoni Arquitectònic Local (SPAL). Architect: Josep M. Moreno Lucas.*



**Figure 2:** *Santa Maria Antiqua*



**Figure 3:** *Sant Quirze de Pedret*



**Figure 4:** *Agios Neophytos Monastery*

changes is essential in order to gain the most precise and rigorous knowledge of the building's medieval *facies* (Figure 1)

We shall start from the creation of three dimensional digital models that incorporate this information in layers in the form of a database that allows the collection of archaeological, architectural, art historical documentation, textual and graphic data, and analysis from the current state of knowledge of the site.

To this end, we have chosen three sites that summarize the above glossed casuistry and that will serve as testing ground to propose solutions that will make it possible to resolve issues that, to date, have not been analysed in all their complexity. Concrete objectives:

1. Understanding architectural complexity, which is usually regularized geometrically. The collaboration of architects experts in this type of investigations has an enormous interest in order to reach a real understanding of the construction of the building and its structural anomalies.
2. Solve chromatic problems. Different restoration criteria used over the years have resulted in notable differences in the current chromatic perception, even for different fragments of the same ensemble. The analysis of pigments, the arrangement of the pictorial layers and the successive restorations suffered will allow us to digitally specify the original colouring of the paintings.
3. Raise and recommend the resolution of lighting problems. To date, trials have been carried out based on the analysis of natural lighting. We will deal with artificial lighting with light sources such as chandeliers or oil lamps, which produced effects of painting vibration making the images "act".
4. Digitally approach the different perspectives of the medieval building. It is the vision of the laity and the one of the clergy to the most decorated parts of the church.

### 4. Case studies

To reach the objectives of the project, we have chosen three sites that summarize the above glossed casuistry and that will serve as testing ground. On the basis of these case studies, technological solutions will be proposed that will make it possible to resolve issues that, to date, have not been analysed in all their complexity:

The early medieval church of Santa Maria Antiqua in Rome (Italy) (Figure 2), preserves an extraordinary case of pictorial palimpsest, consisting of up to ten layers of overlapping painted plastes, realised during a relatively short perod of life (c. VI to IX), which also poses architectural challenges of visual resolution given that it was transformed in to a church from the Domitianic entrace hall in the Roman Forum to the imperial Palace on the Palatine hill.

The hermitage of Sant Quirze de Pedret in Catalonia (Spain) (Figure 3), with its complex architectural genesis from the tenth century, was decorated at the head of the church at two different times by superimposing a layer on the previous one. The discovery of its paintings, their removal and the transfer to the MNAC (Museu Nacional d'Art de Catalunya) and the MDCS (Museu Diocesà i Comarcal de Solsona) took place at two different times (1921 and 1937) with very different procedures, namely museographic montages and restoration interventions. Later, radical interventions were made to the building, altering the two pictorial phases.

The Engleistra or Place of Seclusion founded by Neophytos - Agios Neophytos Monastery- Paphos (Cyprus) (Figure 4) in the twelfth century part of the original hermitage nucleus later transformed into a monastery. The oratory was excavated in the rock from a natural cave and was decorated, at different times during the Middle Ages, with Byzantine wall paintings. The extreme nature of the site and the irregular nature of the rocky surface that house these cycles, comprising of up to five phases, constitute a fundamental challenge for their digital presentation.

### 5. Methodology

To meet the objective of obtaining reliable models, EHEM will be very strict in monitoring the technical research activity with the assessment of the Art History experts. The conceptual research structure of EHEM includes four blocks (Figure 5), which are not WPs nor the boxes are tasks. **Block 1** incorporates the actions needed to acquire the data and associated information of the temple. **Block 2**
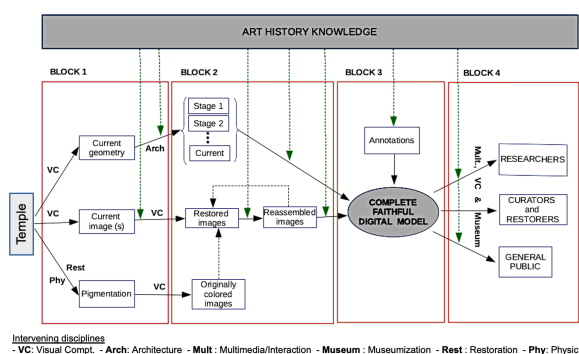
**Figure 5:** *Conceptual research structure of EHEM*



**Figure 6:** *Project's organization scheme.*

embraces the different research activities that deal with generating the faithful and complete models. **Block 3** is about storing and enriching the models in a common open access platform. **Block 4** is dedicated to make results available to different communities.

We organised the project (Figure 6) in five scientific work packages (WP3-WP7) and several functional work packages: management (WP1), specifications (WP2), evaluation (WP8) and dissemination (WP9).

**WP3** encompasses the tasks from the acquisition of images, to settle the paintings onto the digital model of the building. These tasks include determining the material characteristics of the frescoes and grouping in the digital model the pieces of the paintings sparse in different locations. **WP4** includes the digitisation of buildings and their geometry processing to obtain a mesh adapted to the needs of the project. Along with others, this task will require a relevant interaction with WP3. **WP5** is in charge of providing the simulation of the lighting suited to each period and to supply it to the visualisation phase (WP7). It includes natural lighting through openings and artificial lighting produced by different light sources like candles and oil lamps. **WP6** concentrates on storing in an adequate platform that enables to analyse, document, share and enrich the models produced by WP3 and WP4. We foresee to use *aïoli* [†], an open-source software that permits to add semantics for collaborative documentation of pieces of CH. WP6 will provides feedback to WP3 and WP4. **WP7** is intended to present the results to the different targeted users, designing and implementing the suited GUI to each community, guided by the evolutionary approach of the project. WP7 provides feedback to WP6.

## 6. Current work

The EHEM project started (2020) with an accurate analysis of the available data and defining the missing geometry and images. These included the specification and implementation of a complete and complex data base that will provide the semantic and temporal information required by WP6 (Integration). Next phase, the current work, comprises the strongly related WP3 (Reconstruction of frescoes) and WP4 (Reconstruction of buildings).
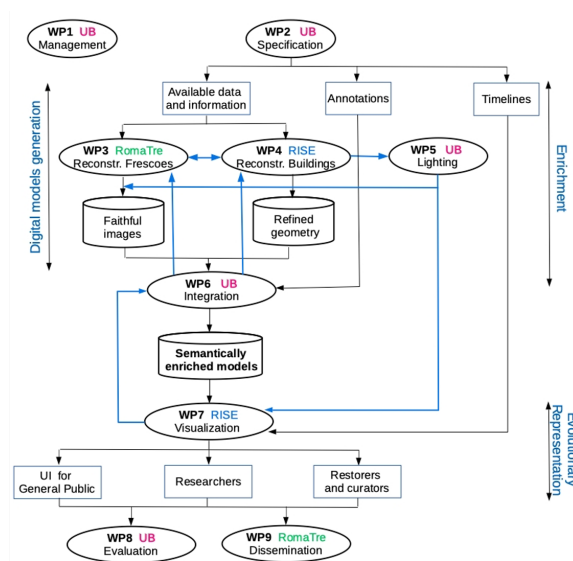


**Figure 7:** *Agios Neophitos reconstruction.*

The outside of Agios Neophitos Engliestra and St. Quirze de Pedret have been digitised (Figure 7). For the Engleistra in particular we employ photogrammetric techniques; to capture the inside of the monument, details of the murals and closeups of the exterior, we acquired around 3000 photographs using a DLSR camera making sure that we had overlap between pictures and uniform illumination. Since we consider the surrounding area of the monastery as very important and part of the monument's history, we digitize the surrounding area using around 1000 photographs taken by a drone. Finally, we digitize paintings and the actual casket of Agios Neophytos from the Monastery's museum. We are currently in the process of building and editing a larger model that will include both the inside and outside of the monument.

St Quirze de Pedret, MNAC and MDCS frescoes were digitised using a LIDAR scan (Leica RTC360) that provides intensity and color information. But some problems arised on that point caused by the tricky illumination conditions: different sites with differents illumination conditions that combines natural lighting (with small windows) and different types of spotlights. This conditions affect not only each individual scan, where extreme lighting range can not be solved with traditional tone mapping techniques, but also in the combination of several scans where this problems are even more noticeable.

[†] http://www.aioli.cloud/

**Figure 8:** *Photograph and HMI acquisition in MNAC.*



**Figure 9:** *Inspection of St Quirze de Pedret pointcloud.*

To solve that, we have introduced photogrammetry to be combined with the LIDAR reconstruction to improve color representation of buildings and frescoes. Although the color representation improves, it is still far of a realistic representation. In the following steps, we will study how to improve color representation of scanners and photographies. On one hand, studying new tone mapping operators that take into account characteristics of cultural heritage sites and, on the other hand, improving callibration and color representation of photographies, being aware of seamlessness [PGC11].

In this direction of improving images quality, WP3 included the development of an acquisition protocol for photogrammetry, for the 3D survey and for the photographic campaigns to use the same parameters for visualising the wall paintings of the three case studies. Following this protocol, the shooting of the Spanish and Cypriot sites has started. At the same time, the photographic campaign in the MNAC and in the MDCS is underway to acquire images of the paintings detached from the Pedret church together with the colour surveys (Figure 8). This will be carried out with a Hypercolorimetric Multispectral Imaging (HMI) approach created by Profilocolore and setting by the team of DEIM departement of Tuscia University [RLM*21] ‡. This is an innovative multispectral imaging technique that allows various types of surface investigation including accurate colorimetric measurements of the surface with $\Delta E_{00}^* < 2$ (CIEDE2000). Contrary to traditional colorimeters, this instrument does not require contact and can return colorimetric measurements for each pixel of the image, process thematic maps and clustering as a function of the $L*a*b*$ values associated with the spectral reflectance measurements of the surface. For the paintings covered by the project, we will analyse sample surfaces that will allow to produce distribution maps of pigments and chromatic backgrounds for the analysed surface and to monitor the colour before and after any restoration work. The colour investigations will provide an essential basis for procedures with the calibration of images placed on 3D models and to propose virtual restoration solutions.

During reconstructions and visualizations of the Engliestra we plan to add vegetation, water and physical phenomena to enhance the realism of the reconstructions. We demonstrate in both Figure 7 and a short video§ some initial 3D visualizations. Some of our 3D models benefit from a fast and robust photo-to-LiDAR registra-

tion [CT*20], which can be used to project high-resolution color onto accurate LiDAR models. We have also explored the registration of user-provided photos to facilitate the authoring of video-based short stories for 3D scanned cultural heritage [CCA20]. We have also started some preliminary dissemination tasks. Inspired by [DLD*13], a student's project developed a web page (based on Potree Library [Sch15]) to inspect St Quirze de Pedret pointcloud (Figure 9).

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‡ https://www.profilocolore.com/
§ https://vimeo.com/538552468