

# SPACE THROUGHOUT TIME, APPLICATION OF 3D VIRTUAL RECONSTRUCTION AND LIGHT PROJECTION TECHNIQUES IN THE ANALYSIS AND RECONSTRUCTION OF CULTURAL HERITAGE

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### ABSTRACT

Since its creation in 1999, Santa Maria Cathedral Foundation in Vitoria-Gasteiz has been committed to a process for restoring the monument that is characterized by the application of compatible new technologies to the conservation of cultural and historic heritage. Concepts related to three-dimensional visualisation, representation and management have been part of this project since the very beginning. Therefore, a 3D model was created using photogrammetry as a basis for the later development and management of multidisciplinary studies. All this information was digitalised and linked to a cartographic model, creating a System of Geographical Information about the Monument (SIM). A series of applications based on 3D mesh models in mesh has also been developed to help the development of the restoration project and its public diffusion. The most recent of the many initiatives that have been carried out is the development of a light projection system for the historical reconstruction of the polychromy applied to the cathedral's portico. This system is the result of a study in which specialists and companies from different disciplines have taken part. This research has revolutionised the interpretation of chromatic integration of monuments. This document provides a detailed description of the entire process the Foundation has undergone since it decided to research different possible methods of projection until the final light projection project was materialized.

## 1. INTRODUCTION

The restoration and protection of cultural heritage in general, and monuments in particular, is an increasingly important issue for society. A series of documents and statements were created during the last century which gained international recognition and are crucial to understanding the work undertaken on this matter by Santa Maria Cathedral Foundation. For example, article 2 of the 1964 Venice Charter could be highlighted among these numerous reflections and indications, *'The conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage'*, as could article 10 of the Charter of Krakow, which states *'Conservation-preservation techniques should be strictly tied to interdisciplinary scientific research on materials and technologies used for the construction, repair and/or restoration of the built heritage. The chosen intervention should respect the original function and ensure compatibility with existing materials, structures and architectural values'*.

Santa Maria Cathedral Foundation is responsible for managing and developing the restoration plan for Cathedral of Santa Maria in Vitoria-Gasteiz. Santa Maria Cathedral Foundation was officially established in 1999 and includes Álava's local council, Vitoria-Gasteiz town hall and the Vitoria-Gasteiz bishopric. The institution represents a basic tool for the architectural and socio-cultural recovery of the building and its surroundings.



Visitors in the Cathedral's nave

The origin of the restoration lies in the Restoration Master Plan for Cathedral of Santa Maria which was drafted in 1994-1998 and in which more than 25 work teams were involved. It aimed to discover the building's current state and historical-constructive evolution, and propose a restoration process for the temple. These studies won the 2002 Europa Nostra award, which is the highest accolade given to conservation work and the improvement of cultural heritage by the European Union.

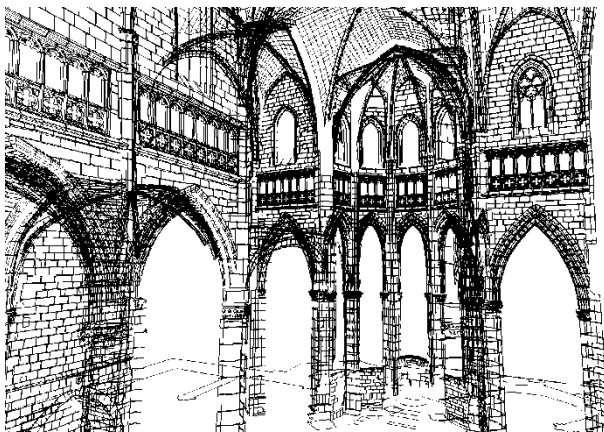
The success of the restoration of Cathedral of Santa Maria lies in the fact that the project didn't merely address the simple

architectural recovery of a gothic church. Instead, it was an integral project that aimed to give the building back its religious function and also develop its potential in terms of its cultural, touristic and museum use. The proposal, (that has been planned during the works phase) is generating multiple positive effects in various fields such as cultural, touristic, scientific dissemination, local economy and urban regeneration of the surroundings.

At the same time, the whole process has developed in a manner that is accessible to the public as part of the 'Open for Works' programme, which aims to spread the project and involve the public in it.

## 2. 3D PHOTOGRAMMETRY MODEL

The use of three-dimensional representation and visualisation techniques has been a common aspect of the entire restoration process at Cathedral of Santa Maria. Thus, when it was decided that the restoration project should begin, it was deemed necessary to create a complete geometric information system about the building. This involved the use of photogrammetry to create a 3D model of the interior and exterior of the Cathedral. This provided a precise replica of the Cathedral that allowed us to see the spatial layout of each stone and the distortion of each element of the building <sup>(1)</sup>.



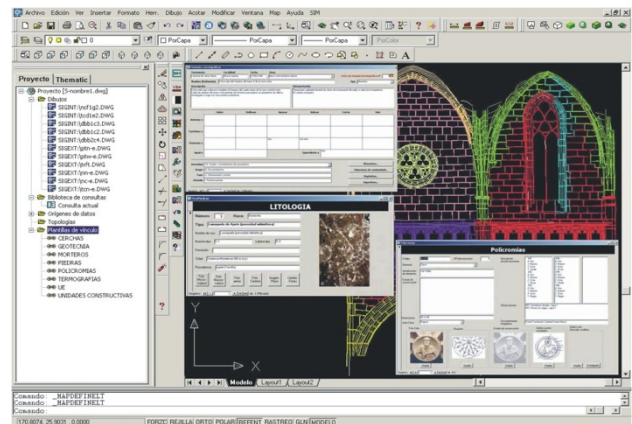
3D photogrammetric model of the cathedral

## 3. SIM. SYSTEM OF INFORMATION ABOUT THE MONUMENT

The study of the Cathedral's current state used information taken from the 3D model to minutely examine the fabric of the Cathedral from different angles. Among other things, this showed the lithological map, the composition of the mortar, maps of plant colonisation, waste systems, a study of wooden structures, etc. All these data were included and organised on a database management system and geo-referenced on the 3D model to create the GIS (Geographic Information System) about the Monument that we call SIM. This system allows us to access the information related to each stone in the building and also to create thematic plans about a specific characteristic (type of stone, construction unity, stratigraphy unity, etc).

The model of the Cathedral is not intended to be static and unchanging. As the restoration takes place, the model is updated, allowing us to see the Cathedral's evolution over time. SIM doesn't just organise the information gathered about the

monument, but also incorporates relevant data on the treatment of the Cathedral's materials and expiry dates. We can thus create a planning for future interventions on the cathedral, this way the SIM pulls together the information about the monument and the management of its restoration and maintenance.



SIM. System of Information about the Monument

## 4. 3D MESH MODELS

The availability of a 3D photogrammetric model has facilitated the creation of 3D mesh models for visualising and analysing constructive solutions for the monument's restoration. In this respect, the Foundation has promoted the creation of different applications, for example:

- Real-time applications;
- 3D modelling of constructive solutions;
- Graphic reconstructions of elements to be restored; and
- Photo-realistic computer graphics.

The cathedral that we can see today is the result of numerous interventions throughout its history. The monument's constructive development and the distortions that have different causes are an essential part of the Cathedral's history and are often the focus of study and representations.

This implies that when planning to create a 3D mesh model mainly for visualisation purposes, the modelling process must bear this in mind. As such, it should be different to the modelling process for a new construction. We will now look at the general process followed for this task.

### 4.1 Process for creating 3D mesh models

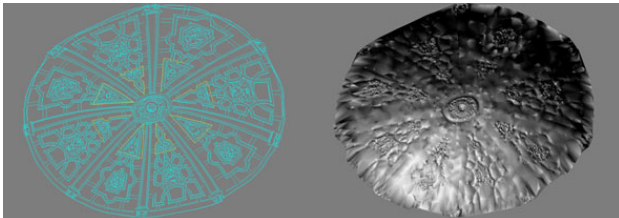
The process for creating 3D mesh models is similar for every application. In general, the photogrammetric 3D model is used as a base for generating geometry. In our experience, it is generally necessary to generate new entities for the final mesh elements in order to check the process and the end result.

First, a generic 3D modelling application is used to import the graphic information from the photogrammetric model (usually poly-lines and CAD drawing elements) so a mesh modifier can then be applied. This creates a series of 3D mesh models that have a complex appearance and composition. In the best-case scenario, the generated mesh will be used as a final element of the mesh model after it has been simplified.

Once this rudimentary mesh has been created, it can be used as the basis for comparison in order to check that the location and shape of the modelled elements. At the same time, the 2D

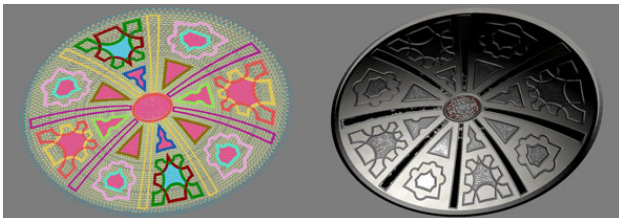
shapes and 3D lines are drawn, which provide a basis for generating the final surfaces through extrusion, loft objects and Boolean treatment of the mesh.

The resolution of the mesh is defined in terms of its final application. For example, if the model is to be used for a real-time application, it must have a limited number of polygons to facilitate the machine process and give the application a greater number of fps (frames per second). The primitives of the generated elements should always be kept so that their density can be modified later on as necessary.



3D linear photogrammetry model

Mesh generated directly from the lines of the photogrammetry 3D model



New mesh generated with 3D software

New mesh, displacement maps and textures

SIM's photographic information should be used in the case of complex elements like statues or facades. Displacement maps, based on orthogonal photographs or restorations, should be used for elements sculpted on facades. They can be modified later, if necessary. The process consists of generating a greyscale depth map based on the original photograph, which is touched up to highlight or minimize elements related to the Z co-ordinate. Generic photographic touch-up applications can be used to do this. If the mesh model is to be used in real time, or the synthetic image to be used doesn't require close detail, a textured depth map is applied to reduce the number of polygons. If the model is to be used for a photographically realistic image, a polygon-generating depth map is used.

Sometimes, generally in the case of statues, a laser scanner has been used to obtain a complex mesh that is later simplified.

#### 4.2 Obtaining textures

SIM's photographic information is again used to generate textures. Using available photographs, initial-state textures (prior to the restoration process) are generated. These textures can be modified to generate the intermediate and final states. Finally, in the case of polychromed elements, these textures are used as the basis for generating polychromes.

If necessary, commercial textures can be used and modified to reconstruct the textures of damaged elements.

#### 4.3 About software.

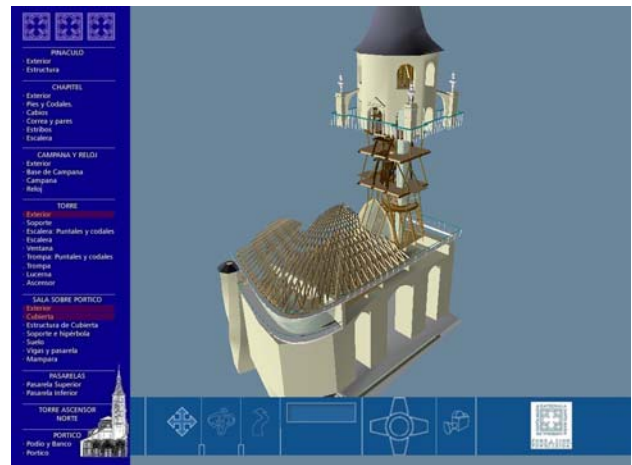
It must be pointed out that in our case the real restoration process is the most important aspect of the project. The use of any method is aimed at improving the process and thus the use of methods, some of which are economic, should be optimised. In this case, we have used standard software. In the case of graphic elements represented by SIM we used standard

Autodesk Map 3D; in modelling 3D mesh we used 3D Studio MAX and Cinema 4D; for real-time 3D motors we used via virtools (in collaboration with other organisations) and a graphic motor developed by a third party; and we used Adobe Photoshop and Corel Photo Paint for photographic touch up and the creation of textures. In this instance, the trend is to continue reducing the economic impact of this phase so that these funds can be directed towards the most important part of the project, and we are currently considering using Open Source tools.

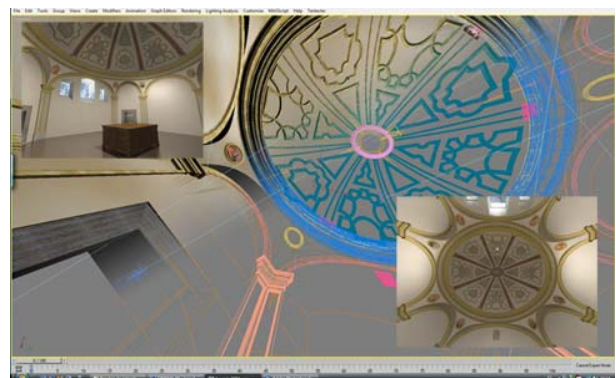
#### 4.4 Practical applications undertaken

To date, the mesh models generated have been used for applications such as:

- The generation of printed material aimed at promoting the restoration project.
- The generation of an interactive, real-time application of the intervention on the tower and the portico.



- The pre-visualisation of renovation options: Sacristy, constructive solutions for integrating the Cathedral with other buildings, etc.



- The generation of photographically realistic computer graphics based on the daft project.



## 5. CHROMATIC REINTEGRATION USING LIGHT PROJECTION

### 5.1 Study of the matching of polychromies

During the restoration carried out in the sixties, the portico of the Santa María Cathedral suffered from systematic scraping that removed any trace of colour. It should also be added that, sadly, no reference samples of the earlier polychromy were left.

The study carried out in the portico was developed by a team of artistic restoration professionals over a period of 18 months. During this time more than 3000 samples were carried out in situ, fully documented through macro- and micro-photography, having performed a laboratory analysis of remains of mortar, samples of polychromies, etc. As a result, a matching chart was obtained that enables us to identify any pigment from any period in history. After this important task, it was clear that the application of colour to stone elements of the portico had been considered an essential part of the portico itself, without which it would have been incomplete.



*Restorer examining polychromy remains on the Virgin through a microscope*

To complement the study, graphic reconstructions have been carried out to show the portico's appearance during different periods. While the work was being completed and the technicians of the Foundation were receptive to proposals relating to the restoration of the portico, we saw a light show carried out in the portico of Amiens Cathedral. The team of restorers that had carried out the study dreamed of uniting the concept of chromatic integration used in restoration with the magnificence of the Amiens projection. It is precisely the use of light as a method of chromatic reintegration that requires us to fulfil a series of conditions:

- The projected light must correspond with the colour of the pigments. The exact chromatography of all analysed samples must be obtained from the laboratory results, including obtaining the corresponding colour code in CMYK.
- The reconstruction must reflect the portico's evolution throughout its existence. It cannot limit itself to representing a single historical moment exclusively.

To these conditions relating to artistic restoration must be added other technical condition:

- The portico of the Vitoria-Gasteiz Cathedral is a closed space and this considerably limits the use of some projection methods.

### 5.2 Research on projection methods

From this point, we in the Santa María Cathedral Foundation decided to carry out a research project with the overall purpose of achieving a non-invasive, realistic visualisation of the evolution of the chromatic appearance of the portico at different times. The specific objective was to define the limitations and characteristics of a chromatic reintegration system using light projection.

People and companies <sup>(II)</sup> from different disciplines worked together on this process, and their work was crucial to its satisfactory conclusion.

The research covered two areas: slide projection and digital video projection. A tomb in a chapel inside the cathedral was chosen for testing. It should be remembered that the cathedral portico was completely covered with scaffolding from 2000 to 2007.

a) Slide projection. The slide projection system is an optical mechanical system using a light source and a slide in a frame. The procedure is as follows:

- A photograph is taken of the object, and the focal length, the x, y and z co-ordinates of the centre of the lens, and angles of inclination of the camera are recorded.
- The slide is digitalised.
- The image is coloured, creating a graphic reconstruction of the object.
- A slide is created, with the added colours, eliminating the original background image.
- A projector with identical optics to the camera used projects the slide from the same position and at the same angles as the original image. This process requires a series of manual adjustments in situ in order to line the image up exactly with the object.



*Slide projector test*

This procedure gives very satisfactory results in terms of light intensity and temperature, but has the limitations inherent in an analogue system.

- If we want to show more than one scene we must ensure that the different slides coincide exactly, both in the slide mounting and in their position in the projector. The slightest movement produces a mismatch, invalidating the method. The projector manufacturers whom we consulted told us that no product exists which can guarantee this kind of stability continually.
- As we mention above, in this system we need to create a slide by applying colour to a digitalised image. This can be done only by specialist photography labs, meaning that the colours cannot be adjusted in real time on the monument.

**b) Digital video projection.** The projection system receives a video signal and projects the corresponding image onto a projection screen using a lens system, enabling still or moving images to be visualised. There is a great variety of video sources now available, including personal computers, our favourite option.

The procedure is similar to that of slide projection, but the mechanisation processes are simplified, enabling the digital image to be coloured directly, and shown in the projector without any intermediate mechanical processes.

This system is optimal for productions based on series of images, as it achieves total projector stability, but unfortunately there are other drawbacks:

- *Projector resolution:* The number of pixels which can be projected. A pixel is the smallest single colour unit forming part of an image. This can mean that the size of the projected pixel can be larger than the detail to be coloured. Associated with this limitation, there is a problem in the projection technology which creates a grid between the pixels forming the image.
- *Colour quality:* The colour quality offered by analogue media is superior to that offered by digital projectors so far.



Using Digital projection both the pixel size and the projected grid can be noticed

The great advantage of this system is that with this type of technology, time is on our side. In the time from the start of our research to when we carried out the installation, video projectors have developed quickly, enabling us to use very powerful, high resolution projectors at a price which makes the project viable.

An important part of the research process was a project developed jointly with other organisations <sup>(III)</sup> to explore the technical viability of a visualisation system based on virtual reality and augmented reality technologies. This system would enable the polychromy of the portico to be represented, but the information provided would not be a physical image (as in earlier proposals) but an exact replica of the portico obtained by precision 3D scanning. The process would be completed by the addition of the different layers of colour on the 3D model and with a management system which can show the image of the portico in any era from any point of view. The project was shown to be technically viable, but the economic cost was too high for it to be taken on at this stage of the project.

### 5.3 The proposal

Our research into the conditions imposed by the techniques of the different projection systems and the tests carried out enabled us to explore the advantages and disadvantages of each option.

This was when the project took its definitive form, settling the characteristics of the system for chromatic reintegration by light projection to be implemented in the portico of the Cathedral of Santa Maria.

**a) Place: the Paternina chapel.** The projection of the entire portico remains one of our goals, but is not presently a viable part of our project to restore the Cathedral, too many projectors would have to be used to cover all the space. It is technically viable, but in economic terms the cost would be much higher, and aesthetically it is unacceptable. The best location for this representation is the Paternina chapel (in the portico itself), where the visual impact of the projectors is minimal and it is the area of the portico with the richest polychromy (except the sculpture of the Virgin in the central tympanum).

**b) Technology.** Visitors should perceive the colours in the same way as the experience of seeing a polychromed portico; i.e., they should perceive the colour as if it were pigment, rather than projected light. To achieve this we opted for digital video projection with high resolution projectors and a DLP system with 3 chips. This meant improved contrast and depth of colour compared to LCD-based projectors. The choice of 3 chips rather than 1 influences the range of colours which can be shown and the useful life of the projector. Digital projection enables colorimetry to be adjusted in situ, and the problems arising from the resolution of the equipment are practically invisible when observing the projection. Economically, the use of these high-end commercial projectors is expensive, but not prohibitively so.

**c) Impact on the monument.** Any installation in the cathedral must consider that it is a historic monument and that many of the usual solutions cannot be used here. Aspects to be considered include the types of fixing elements used, projector size, placement, location in the space and any other relevant consideration.

d) Visual impact on the monument. Visitors must feel themselves to be in an immersive environment similar to a polychromed portico, so the visual impact must be minimised. There would be little point in perfectly realistic colours if observers have the projector in full view at all times or if there is a constant roar of fans.

e) Flexibility of the system. The system should not be closed to new projections. One of its greatest potentials is the possibility of representing proposed work or of highlighting different single elements in the portico.

#### 5.4 Execution of the project

Once the scope of the project was defined, there was a tender for the installation of the system. This was when final decisions were made on the details of the implemented system.

a) Equipment: 4 DLP video projectors with 3 chips, with SXGA+ resolution (1400 x 1050 pixels) and 7000 ANSI lumens. Each projector is controlled by a computer in a control room located in an annex to the chapel. The system is managed by an automation-control system using a touchscreen. It also includes software for monitoring and developing applications with the different apparatus

b) Spatial distribution. The spatial location had to consider the need to respect the monument and the aesthetic aspect. We chose to place the projectors at the sides of the chapel, in a bronze cabinet and raised slightly above the floor. Other bronze elements have been included in the restoration of the chapel, as this material is compatible with the space. The control equipment, consisting of 4 computers and a sound system, was located in the control room, and the cables required were passed through a duct made under the paving stones of the portico, so there are no cables visible.



3D model to visualise the visual impact of the projection system

c) Configuration of the equipment. Once the projectors and optics are installed, the light projected should illuminate the entire chapel. In many parts of the monument overlaps of light from 2, 3 or even all 4 projectors will appear. When we project the polychromy, the light projected must be completely homogenous, with no overlap appearing in any areas. The projectors must also have a system which can identify their exact position at the time of calibration, in order to avoid any accidental movement rendering the system unusable

This is carried out in various phases:

- *Registry and alignment of the projectors:* Once the projectors are fixed to their bases, a registry system must be created in order for their initial position to be referred to. This information will be essential when the projectors change their initial position, whether accidentally or due to maintenance. To do this, a series of control points are noted all over the projected area. This pattern makes it possible to readjust the projector to its original spatial parameters.

- *Creation of a mask* to avoid light pollution from other projectors. Initially, each projector uses a 4:3 format, but not all of the lit area belongs to the Paternina chapel. In this phase we adjust the intensity of projection so that all points of the model are homogenous. For this, in some cases masks are used to eliminate light in areas which are not part of the polychromed model, and in other cases, the light is dimmed for overlapping areas of projection.

- *Drawing a linear model with all the contours which appear in the chapel.* In this phase base files are created with all the geometrical information of the model. This information is generated in situ, using the walls of the chapel as an editing screen and almost literally drawing on the elements of the chapel. This means we will have an image file for each projector with all the contours defining the geometry of the portico. These files can be used as a template for generating moments in the history and aesthetic evolution of the chapel.

d) Creation of new polychromed scenes. We give the name of polychromed scenes to the set of images (one per projector) recreating the appearance of the Capilla de Paternina at a given time. Studies of the correspondence of the polychromy identify up to 15 overall interventions in the nearly seven hundred years of the portico's existence. To do this we use the templates generated in the last phase and apply the colours of each element in the corresponding place. Finally, the definitive colour is adjusted in situ, as the resulting colour depends not only on the projected light but on the texture of the surface. This phase is carried out under the direct supervision of the head restorer, who is the person most familiar with the variations in colour.



Restorers control the adjustment process for the polychromies

e) Audiovisual production. In this last phase, all the graphic resources will be assembled in a sequence of images recreating the polychromed eras we want to see in the

portico. This task uses multimedia creation software enabling the synchronising of content, the integration of information in different formats, and the production of high quality audiovisual material, making the journey through time even richer and more educational.

**f) Starting up.** The control room next to the chapel allows access to the unit controlling the system, which is programmed for automatic execution of the different audiovisual productions. A touchscreen is used for the user interface. The four computers managing the projection are accessible by remote control using a LAN (Local Area Network).

### 5.5 Epilogue.

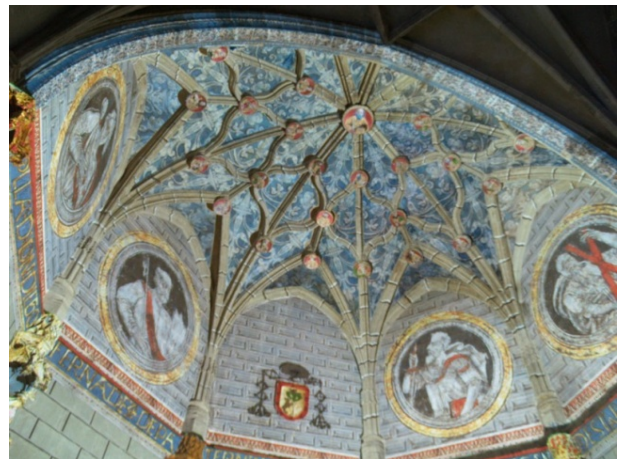
The study of polychromies matching was carried out from 2003-2004 and the process of restoring the portico continued until late 2007. During 2008 technical papers were completed, details of the awarding of the installation were finalised, and in December the installation began. In January 2009 the system was fully installed and 2 polychromatic scenes had been carried out and fitted. In February the multimedia productions will be carried out and by March 2009 these will be incorporated to guided tours of the Santa María Cathedral “Open for works”.

The result obtained is spectacular and has been well received by technicians and restorers who have seen it, in the images shown you can appreciate the quality of the presentation.

Within the artistic restoration world, the use of digital video projection techniques as a form of chromatic reintegration allows you to see, on the monument itself, the appearance that this monument had during a specific period. But this is not the only possible use as the system is interactive. This allows for the creation of coloured models that do not correspond to a documented study but that allow the presentation of work hypotheses and also for contemporary art colour projects to be carried out using the Patemina Chapel in the portico of the Santa María Cathedral as a base. The list of possibilities is immense with the portico and the colour as common denominators, a partnership that has always been present in Santa María and that now has been renewed.



Light projection detail



Light projected polychromy on the chapel's vault



Photograph of the Paternina Chapel while the light projected recreates the original polychromy of the XVI Century

## 6. ACKNOWLEDGEMENTS

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II The following people and companies have collaborated in the development of the the investigation about light projection techniques:

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 AIDAZU S.L. (Light and sound systems).  
 PETRA S.Coop. (Artistic Restoration) [www.petrarestauracion.com](http://www.petrarestauracion.com)  
 Philips  
 QUINTAS Photographers (Photography)  
 E-TECH MULTIVISION (Digital projection and shows). [www.e-techmultivision.es](http://www.e-techmultivision.es)

III EUVE (European Virtual Engineering, S.A.), SUBIPRO S.L. & Santa Maria Cathedral Foundation, FIT-410000-2004-44, "Visualization System for touristic installations based on Augmented Reality and Virtual Reality".

Photos: Santa Maria Cathedral Foundation, Quintas Fotógrafos, José Manuel Navia

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