

PICTORIAL RESTORATION OF FRESCOS BY TRANSFERRING INKJET PRINTS: THE CASE OF PALOMINO'S FRESCOS IN THE CHURCH OF SANTOS JUANES IN VALENCIA

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ABSTRACT: *The case of the burnt frescos from Palomino in the church of the Santos in Valencia is a challenging problem that requires drastic new alternatives to traditional means of wall restoration. Very little is left untouched in this particular case: basically one document containing historic graphical information, and a few real references remaining that show the author's technique (around 30% of the fragments). Using new inkjet-based technologies for digital imaging we reconstruct the missing elements and bring to life the appearance and context that once made this a very beautiful masterpiece. A new methodology been established that coordinates a perfect synergy between the different computer systems involved (digital camera, computer and printer), while simplifying the transfer to wall procedure that allows a harmonious coexistence of the current remaining fragments and the recreated ones.*

KEYWORDS: wall painting, frescos restoration, inkjet technologies, inkjet transfers

1. INTRODUCTION

Since 2005 when restoring of the vault frescos in the Santos Juanes church started, a number of articles have been published concerning the progress of this activity, research results and proposed solutions for exhibition and conservation. This paper describes the latest advances in the process of reconstructing the missing elements of Antonio Palomino's frescos.

2. METHODOLOGY

The process of pictorial integration by inkjet transfer is a result of the collaboration of the *Talleres de Intervención de Pintura Mural y Documentación y Registro del IRP*, Hewlett-Packard research and development engineers and the company *ARSUS PAPER*. The method consists of three main stages:

1. Photographic capture and image processing using 'HP Artist' software on the remaining original fragments
2. Composition of a digital image to transfer
3. Printing and transferring

2.1. Method of photographic capture and image processing with HP Artist software.

The digitization and colorimetric reconstruction of original fragments has been done using a Hewlett-Packard technology that allows digitization of fine arts pieces in a simple manner, with low costs and highly reliable results. The system HP Artist [DiCarlo, Sampat et al, 2004] reduces the need to perform manual corrections after the capture process, which minimizes the long and expensive cycles of trial and error. It also requires less artistic skills from the operator to

decide when a digitization still requires color corrections before being printed. In general it also makes the capture process simpler since the positioning of the lights involved in the capture process is less critical.

In essence the system was designed to reproduce paintings and other fine art pieces such as ancient books and artwork, but its simplicity and portability has enabled it to be used for the Santos Juanes project, where traditional reproduction systems such as the multi-spectral with special cameras and devices cannot be used. The system works with a far more portable Nikon D2Xs SLR camera that allows the photographer researcher to take the pictures in the restoring environment using a scaffold adapted for a complex architecture and structure where other heavier and more sophisticated devices could not be used.

2.1.1. Method

After the traditional fragmentation into quadrants of the working area¹, the capture process consists of taking two consecutive pictures per quadrant under the same lightning conditions. The first of the two pictures captures the fresco, while the second one captures a white surface that we refer to as the reference. Normally we use a canvas or flat surface that is bigger than the area to reproduce, but the exceptional conditions in the Santos Juanes required greater inventiveness. In the end a sheet of large format media mounted on a flexible PVC frame was used.

The capture of a white reference zone for each original capture is critical in the process defined by the HP Artist software. The system performs automatic light compensation correcting all non-uniformities in each quadrant area. In this manner the capture becomes independent from the physical location of the illuminants². Usually in the reproduction of fine arts there are at least three illuminants that have to be placed

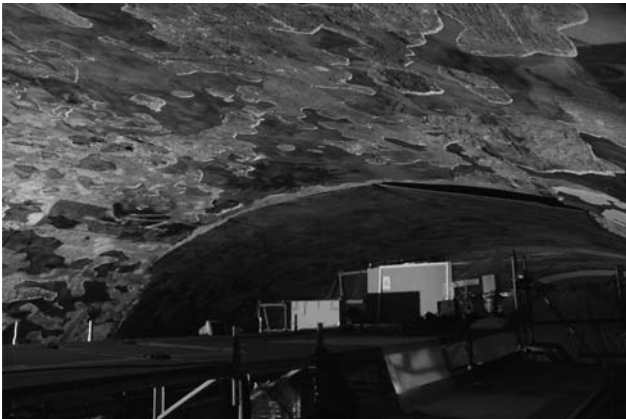


Figure 1. View from the scaffolding of a work area



Figure 2. Photographic capture process

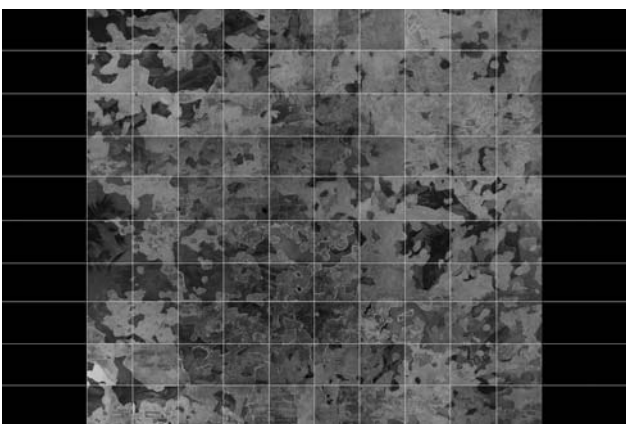


Figure 3. Mosaic photography. Central area of the vault. Approx. 90 m²



Figure 4. Grid drawn in the vault



Figure 5. Points collection through the topographical station

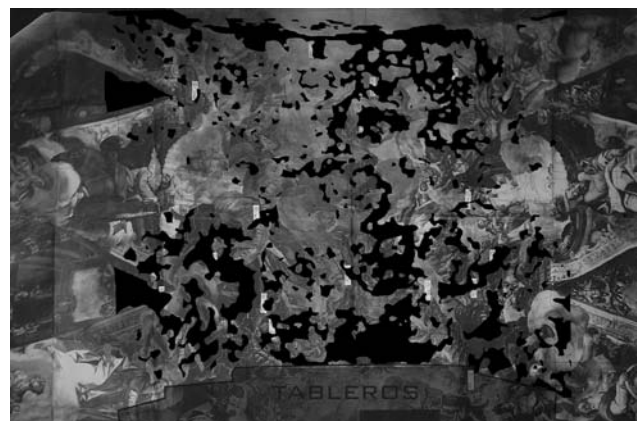


Figure 6. Selecting points in the paint for georeferencing

with certain precision around the surface to reproduce, so that incidental angles of light are around 45°. Hence non-uniformities are to be corrected prior to the capture by manual compensation that is measured by a hand light-meter. The conditions of work in the Santos Juanes church make it very difficult for the photographer researcher to place these illuminants accurately. However, using the HP Artist software this problem is solved; at the same time there is no need to verify that the intensity of light in each point of the quadrant is the same.

As part of the process, we also need to take sample measurements of the reflectances in the remains of the original, which is done easily with a manual spectrophotometer that measures reflected light in a set of at least 60 random points that help the system characterize the nature of

the pigments in the original remains. Knowing how they react to light lets us understand how to reproduce their colors and how the camera is behaving with regard to these elements. Most of the cameras are designed to work with any type of situation and scene, often giving volume to flat images as they are captured by the sensors, e.g. a face, and adjusting the skin tones, hair, etc. to the user's taste. Often these variations depend upon which side of the world the picture is taken, e.g. interior lights and temperatures in Japan are not the same as in Europe, and this has an impact on the captured image.

In the artistic-scientific cases where reproduction is involved, either for restoration purposes or simply to analyze the work, the main goal is achieving a high-level of accuracy in the capture as compared to



Figure 7. Process assigning referential points

the original. The HP Artist system automatically compensates and corrects the images generated from the camera comparing them in XYZ color space against an emulation of how the human eye would interpret the real images based on the measured reflectances.

If we assume that all remaining pieces from Palomino in the Santos Juanes church were always done using the same type of pigments and pictorial techniques, the measurements of reflectance in the remaining originals must be carried out once only and reused. This can be done in places where the access to the original will not be a problem. As regards the number of samples to take, there are no significant improvements after taking 50 or 60 measurements. In our specific use case the work was done using a colorimetric scan with a Minolta 2600d spectrophotometer with 60 samples.

Using the image of a quadrant section of the original fresco, an image of a white reference for this section, measurements of reflectance in the original wall, and measurements of reflectance in the white reference, the HP Artist system will generate an automatically corrected image of the original fresco in the quadrant. Optical deformations that can be produced through effects of illumination or camera will also be corrected; the system uses a set of profiles that characterize how the camera and lights will perform. After that, a massive correction is applied to each section of the quadrant reusing the elements of reference that are repeated. A last step prior to generating each final image in the quadrant consists of the sharpening that is done to improve the results, an automatic step that also depends on the type of camera used. For the Nikon camera images the unsharp mask parameters amount to 300% with a radius of 1.0530.

The HP Artist system generates an input color profile embedded in each image that is optimum for each of these images of the quadrant, optimum taking into account lightning, position and other characteristics of each section of the quadrant. Each final image contains an ICC profile that is unique, hence its greater accuracy when comparing the original at the moment of printing – as a reference, let's consider that commercial cameras use the same ICC reference profile for all images generated, a professional photographer may profile the camera in a given lightning condition, but this is impossible to escalate if the process needs to be repeated for each of the quadrants of the fresco surface. In addition, the HP Z3100 series inkjet printer used in the restoring of the Santos Juanes church contains an embedded spectrophotometer that operates automatically, is easy to use, and affords consistent output in each of the prints that will recover the whole surface of the vault, providing optimal image quality and matching with the remains, a controlled color path from the initial capture to the last of the print outputs.

2.2. Composition of the image to transfer

The image to transfer is created from the scan and enlargement of a black and white image from the 30's taken by the photographer J. Alcon that is today the last remaining example of how the vault from

Palomino was originally. From this single image and the captured pictures remaining from the fresco, the final composed image is created. After enlargement of the black and white image, the captured fragments will be placed within context, and its palette colors and chromatic characteristics will be used to fill in all the colors in the image. The following steps are necessary:

2.2.1. Geo-reference of the digital image from the vault

To perform the positioning, correction, unskewing, and enlargement of the black and white image we use software that allows both editing and correlation of geo-references, i.e. assigning different points within the image with a set of geographically identifiable control points in the physical space. There is a large number of applications that could be used for this purpose, most of them combining geo-referencing and teledetection activities, in this particular case we adjust the image in black and white only using geo-referencing activities.

The techniques required to perform geo-referencing require high levels of accuracy in some of the measuring tasks. One fact to bear in mind is choosing the correct set of terrestrial control points (GPC) that in this case consists of points still existing in the original fresco.

The *Microestation* software solution combines both geo-referencing and teledetection activities through a subprogram called *IRAS_C*. The choice of the *IRAS_C* software package is not only based on its ease of use, but also on its being one of the most complete packages for geo-reference tasks currently existing.

2.2.2. Choice of the geographic points of control

It is very important to bear in mind three areas when choosing the control points:

- The number of points
- The location of these points
- The distribution of these points

These three facts depend on the complexity of the working scenario. In this case, the scaffold installed does not allow access to some of the control points for measurements. The more reference points we have, the better results we can obtain in relocating original fragments within the enlarged black and white scan. It is important that the distribution of these control points is uniform within the image, covering the whole of it. Using a topographic measurement station a number of control points are taken, these points are present in the vault and distributed around its surface in a network of quadrants that are marked on the wall.

Once the whole of the network of quadrants is mapped in the software, a set of points uniformly distributed around these quadrants is selected to help fit the quadrants into the enlarged black and white picture. However, there are many areas where there is no pictorial fragment left at all. For this task a set of 25 points has been selected.

2.2.3. Geographic correction

With all the data taken the software *IRAS_C* calculates the position and coordinates of each of the pixels in the image to transfer. This requires some transformations to project the digital image into a geographic space. These transformations allow us to change the complete geometry of the image with a good deal of flexibility.

2.2.3.1. Unprojection of the original image

The *IRAS_C* software will insert the original B&W photography into a virtual geographic space created in the computer with perfectly identified coordinates. It also processes each fragment of the photography separately to allow a perfect adjustment. After the photography is adjusted and processed for each section in the network of quadrants, the mosaic composed by all of these fragments makes up the final complete image.

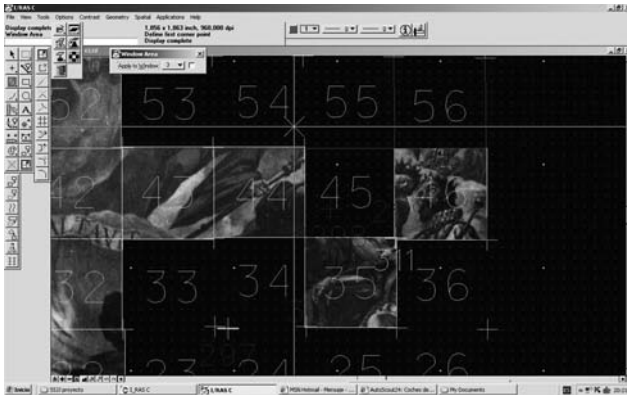


Figure 8. Cropping the composed photograph in quadrants

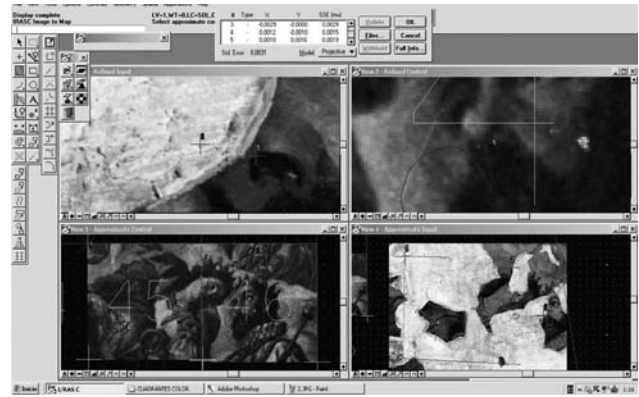


Figure 9. Adjust of the photographic scan



Figure 10. Mounting an captures area on image B/W

2.2.3.2 Cropping the composed photograph in quadrants

To facilitate the printing and transfer operations, the digitally composed image is cut into areas that match the quadrants existing in the vault. These quadrants have dimensions of 88 x 86 cm.

2.2.3.3 Adjustment of the photographic scan

Using the same software, each of the images captured from the remaining originals is processed after treatment using HP Artist. In this manner, the color corrected images are un-projected (or virtualized) in the computer so that they can be placed in the correct context in the enlarged image of the vault. Assigning a set of strategic points – combining visual references with quadrant alignments – we achieve the adaptation of each of the images to the network of quadrants.

2.2.4. Digital coloring

To illustrate each quadrant with the correct set of colors, we superimpose a composition of the captured images colored by the HP Artist software onto the enlarged B&W image, both images within the same virtual space of geographic coordinates. A set of color layers is therefore applied, taking as reference the colors from the automatically corrected images – which are as close to the original as possible – on top of the enlarged B&W image deployed. The following steps are required to perform these activities using Photoshop software:

2.2.4.1. Superimposing the quadrants

Open two identical quadrants cropped from their context and make them match on location with the IRAS_C software.

2.2.4.2. Eliminate areas without painting

Once the two quadrants have been adjusted, the areas of the color-corrected image that have no remaining original pieces of fresco have to be eliminated. In this manner we obtain two layers ready to be colored.

Leveling the grey scale

The color layer is de-saturated to allow balancing the light and dark areas from the original B&W image, thus adjusting the grey scale with respect to the image resulting from the color-corrected captures.

Coloring the B/W layers

A set of transparent chromatic layers is created to superimpose the B&W image. To perform this action a set of brushes with greater or lesser opacity and flow is required. Lastly, the final results are applied and the level of detail increased so that the pieces fit as well as possible.

2.3. Printing and transferring the image

In our opinion, Inkjet technology is the most suitable for these types of application (Sánchez, 2003) (Regidor, 2004) today. Inkjet provides versatility (formats and media), stability (durability) and constant evolution in industrial, commercial and home usage. It is becoming the reference for applications in the field of reproduction and restoration of fine artwork.

2.3.1. Printer and ink

There are a large number of requirements for the printing system to be used in this project. From the computer perspective, a high degree of compatibility with the rest of the infrastructure (software and hardware) to be used is important, and most especially there are image quality aspects, such as accuracy, consistency from print to print, color gamut capabilities, the permanence of the inks, the flexibility to support different types of media (among them the selected transfer media for this project), etc.

The printer had to be able to work with pigmented inks with high levels of durability and a composition that would enable inks to be transferred to the wall. Based on these requirements, a set of tests was carried out using HP UV inks in the HP 5500 printer and HP Vivera inks in the Z3100 printer. After laboratory confirmation showed that both systems were suitable, we ended up selecting the Z3100 printer given its high value in terms of image quality,



Figure 11. Adjusted for quadrants



Figure 12. Coloring phase



Figure 13. Print tests

autonomy, reliability, flexibility for larger media, wider color gamut and durability of the inks as compared to the rest of printers in the market.

Z series printers such as the Z3100 have been designed for the graphics and professional market. They have a wider colorimetric color gamut, finer grain and accuracy of the ink drop than other printers in the same range. In addition, prints remain consistent across time and from print to print, i.e. printing the same image many times will provide exactly the same results over time, which is critical to cover a surface of 200 m² in a task comprising several months of printing to provide a single identical artistic experience.

Another interesting characteristic of this printer is its capacity to be self-maintaining and self-calibrating, and to carry out other maintenance routines automatically, which makes the researchers' tasks simpler by letting them focus on other parts of the workflow rather than the printing itself. In this way the printer is another "pair of hands" that provides constant uniformity in the output and availability over the production period.

HP Vivera inks are also a great advance with respect to the UV inks that are water resistant. Initially there were some potential concerns: the water-resistance capacities could impede transfer through water-based means, and the excess in agglutinant that encapsulates the pigment, protecting it from humidity, could create a plastic barrier that would excessively reduce the transpiration of the wall on which the ink is to be deployed³. After these initial doubts had been proven not to be a problem, all of the other characteristics of the Vivera inks evidence its great value for these types of operation.

More than 200 years will have to pass before any variation of color when printing with Vivera inks can be measured with colorimetric instruments. This is based on durability analysis carried out by the Wilhelm International Institute, which specializes in durability analysis (Wilhelm, 2007). This minimal chromatic variation, detectable by instruments, is far from being detectable by the human eye (Wilhelm, 2004). In addition, the fact that the inks are water resistant will also add the value of being resistant to the inherent humidity caused by temperature changes that exists in the frescos of the Santos Juanes church. There will be no chromatic changes caused either by humidity or temperature changes.

2.3.2. The temporary transfer media

Based on the requirements for a work such as this, the requirements were to find a temporary transfer media that would be suitable for inkjet printing over wall plastering.

The objective was to find a temporary transfer media and procedure that would respect the conservation requirements of the remaining original fragments. Bearing in mind that the original remains will be in contact with the newly created ones, the non-damaging nature of the tasks will depend on the following factors:

- Porosity. In the case of undesired humidity, the non-permeability of the treated zones could force mineral salts to migrate right into the original fragments, which would then become the only breathing window in the wall. For this reason it would be necessary that the ink transfer did not require any extra adhesives other than the original mordants.
- Accuracy. Avoid systems that could affect the original conserved zones, both in terms of physical dangers (abrasion, blows, unsafe non-controlled elements ...) and others that could be produced by accidental coloring of the remaining conserved pieces.
- Safety. Especially for the operators doing the physical work taking into account that the ventilation of the vault at the high location of the scaffold in the church would be limited. The usage of toxic elements would certainly complicate the task.

Indeed, the method must offer the following advantages:

- The transfer material adapts to the rough surface of the plastering, volume and irregularities of the Santos Juanes vault.
- The transfer material needs to be elastic, correcting the image in the systematic application of each original fragment, from the 268 calculated.
- It also needs to be transparent, so that the location and positioning of the elements avoids placing the elements on top of the original remaining fragments.
- The color of the transferred image needs to match the intended color previously defined.
- The final appearance of the surface where the image is transferred and the remains of conserved painting have to have the same appearance.



Figure 14-18. Papelgel system

Transferring images with inkjet technology can be done with the following alternatives:

- Transfers based on a temporary support media using thermoplastic polymers. The transfer is done by applying high temperatures (around 100° or 180°) and pressure on the receiving surface. These transfer media are normally opaque, not elastic and usually involve deploying a non-permeable film on the final image. The final appearance is also affected by this layer of film.
- Some transfer media require dissolving the inks with solvent. The transfer is done by applying pressure on the receiving surface. These are also non-opaque and non-elastic media.
- Transfers done using a temporary media on which an adhesive layer is applied before the final transfer. The surface onto which the ink is transferred becomes non-permeable, and often needs a final lamination to eliminate the glossy appearance which results.

For all of these reasons we decided to adapt another material for our specific usage so that all of the requirements described above are met.

THE PAPELGEL SYSTEM

The company ARSUS PAPER⁴ has developed a laminar material copolymer, harmless, transparent and very elastic; PAPELGEL⁵, the solid-gel composition allows the transferring of high-quality photographic images in almost all surfaces and volumes, independently from their texture and porosity, with no prior preparation of the surface.

After two years of joint research by IRP and ARSUS, we have managed to make the PAPELGEL system appropriate, so that there is no need to use any adhesive with it. With this, we have managed to obtain a new material that fulfills all of the above requirements:

- **Harmless.** The transfer of ink after printing is done with the pressure of a roller and distilled water. After this, the transfer media is removed and no residual deposit is left.
- **Elastic.**
- **Transparent**

The system is performed in the following phases:

- Printing the image to transfer onto a roll of transfer media.
- Adding water to the transfer media, cropped for easy manipulation.
- Positioning the transfer material on the final location.
- Apply pressure with a roller to the transfer material.
- Removal of the transfer material.

To transfer the near 200 m² of areas in the fresco, we decided to print 88 x 86 cm areas of surface placed in a semi-elastic frame to facilitate their handling. The frame is positioned on the wall surface to transfer by a simple air suction mechanism.

After the transferring process onto the wall, only the ink remains with its coloring pigments, and specific mordants, these elements and their compatibility with the final supporting wall being what will determine the global stability and non-damaging nature of the printing.

2.3.3. The final medium. The pictorial plastering

To select the final plastering that will receive the transferred ink we did not want to deviate from what the typical and traditional plastering materials are. These are usually based on mortar, lime, sand and plaster.

The principle of being as similar to the original as possible dictates the selection of materials in all restoration activities, and certainly with the Santos Juanes case, so that physically and aesthetically there are as few changes as possible.

The criterion to ensure that the nature of the final medium (traditional wall plastering) prevails over the transfer system has been a challenge for the project.

The ideal plastering would simply consist of a mortar as similar as the one used by Palomino in shape and composition, i.e. a mortar of lime and sand, which in accordance with the analysis performed, would be composed by lime and marble dust in a proportion of 1/1 or 1/2 with a maximum granulometry of 0.6-0.7.

After the evaluation of different variables we decided to work with a mortar of aerial lime and silica sand in the usual proportions.

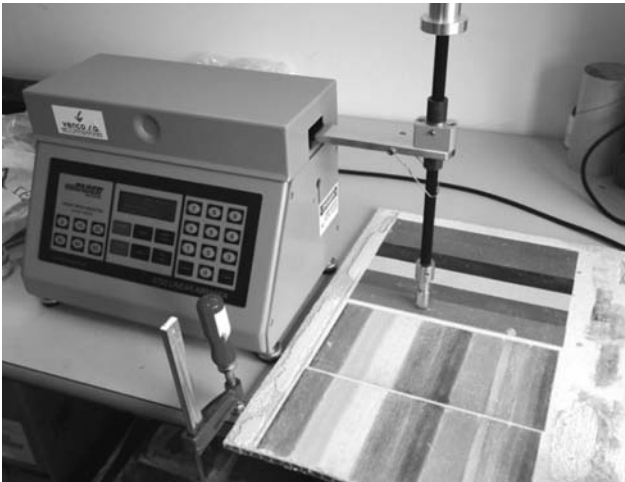


Figure 19. Resistance tests with an abrasimeter

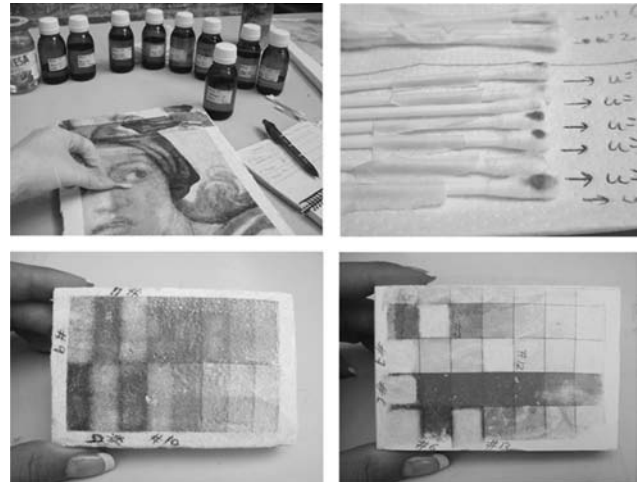


Figure 20. Solubility test

2.4. Suitability of the structured pigmented ink / plastering mural

Different research works vouch for for the stability of inkjet prints with HP pigmented inks UV and Vivera on different media, and the same is known for the resistance of the plastering of lime and sand. However, the combination of both is to be treated as a new problem to research, especially when putting them in context together with original fragments of historic frescos.

The transfer system requires that the ink, initially in a liquid state, solidifies on the temporary media for transfer, and then dissolves again before becoming fixed on the wall support. This forced change of phase and the fact lime-sand walls keep a very alkaline composition (PH 13) for a long time, are facts that can alter the stability of the disposition. To answer these doubts there are research studies being undertaken that validate the suitability of the combination of pigmented inks and mural plastering.⁶

A large number of probes are undergoing cycles of accelerated artificial abrasion (UV lighting, temperature, humidity and polluted atmospheres), comparative chemical analysis, and the evaluation of color changes (ΔE^*) or shine, and are providing very satisfactory results. For example, it appears that the wall plastering is itself weaker than the inks under exposure to polluted atmospheres. It also shows that Vivera inks have greater degree of resistance to UV lighting than the UV inks themselves.

On the other hand we are performing comparative tests to validate resistance to abrasion and chemical products (color transfer after rubbing) that evaluates the resistance to erasing (reversibility) and the influence of different chemical substances⁷. From these experiments we can infer that transfers in general have a moderate resistance to abrasion compared with traditional fresco painting, and very similar (or higher) to dry surfaces treated with aquarelle .

Valuing the resistance against wiping and color transfer after rubbing we have proved that all transfers are sensitive to high polarity solvents such as toluene and less so to water, being unable to obtain total elimination in all cases, as the ink filters through the roughness of mortar, which happens in the same way in aquarelle-based coverings if the support has not been treated with an absorption regulator. Lastly, the older probes (2 years) show greater chemical resistance than the recent ones (3 months), which implies that the gradual forging of the lime mortar and the agglutinants in the inks accentuate the resistance in the transfers.

3. CONCLUSIONS

Using photography as the material to reintegrate artwork is justified by the argument that it is the most loyal element that we can obtain to know how the fresco was originally, at the same time it does not replace, or falsify the character of the painting.

As we mentioned previously, the attempt to reproduce original colors by using inkjet prints transferred from digital captures is an important attempt in the search for perfect harmony between the different computing elements, and we expect these systems to improve over coming years as technology evolves.

The work of Palomino has waited for 70 years for a solution to arrive, and the execution of this proposal can open the door to a definitive restoration that would recover the pictorial ambiance of the Santos Juanes church, doing justice to the valuable remaining elements of the fresco that still are conserved.

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NOTES

¹ The net of quadrants defined on the surface of the wall are of 88 x 86 cm.

² Lights or spots that generate illumination.

³ Bear in mind that one of the objectives of our transfer is that the final plastering in the wall will keep its porosity and transpiration without alterations, both for conserving the actual transfer, and also the original surrounding fresco.

⁴ The firm has become specialised in the works of art reproduction; mural; picture on canvas, altarpieces, mosaics, etc. obtaining the most exact replicas that it is possible to achieve nowadays.

⁵ In summary, the system consists of:

- Tri-dimensional scans of the original to further analyse copies in volume.
- High-resolution photography of the polychromy of the original masterpiece.
- Printing through inkjet systems
- Transferring the image on the achieved volume to ease the transferred image. We used an adhesive that would make the support media become non-permeable.

⁶ ESTUDIO DE SISTEMAS DE TRANSFERENCIA Y SOPORTES TEMPORALES DE IMPRESIÓN INK JET CON TINTAS PIGMENTADAS UV SOBRE SUPERFICIES MURALES. Ref 4722. 20070321 supported by the Vicerrectorado de Investigación Desarrollo e Innovación de la UPV. ESTUDIO DE SISTEMAS DE TRANSFERENCIA Y SOPORTES TEMPORALES DE IMPRESIÓN INK JET CON TINTAS PIGMENTADAS SOBRE SUPERFICIES MURALES Codg. GV/2007/208. supported by the Consellería d'Empresa, Universitat i Ciència

⁷ These abrasion tests have been performed using a TASER linear abrasimeter

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Versión española

TÍTULO: *Reintegración pictórica mural mediante la transferencia de impresiones ink jet: el caso de los frescos de Palomino en la Iglesia de los Santos Juanes de Valencia*

RESUMEN: *El caso de los frescos quemados de Palomino en la iglesia de los Santos Juanes de Valencia, reúne suficientes condicionantes para plantearse un reintegración pictórica alternativa. Existiendo documentación gráfica histórica, referencias reales de la técnica del autor (30% de fragmentos conservados) y sistemas reproducción digital (impresión ink jet), podemos afrontar la reconstrucción de los fragmentos desaparecidos e intentar devolver a esta obra parte de la apariencia que la hizo hermosa. Con el fin de obtener una perfecta equivalencia entre los distintos operadores informáticos (cámara, pc, impresora.) y simplificar el sistema de transferencia se ha establecido una metodología de actuación que permite la convivencia armónica de los fragmentos reproducidos y los conservados.*

PALABRAS CLAVES: *pintura mural, reintegración pictórica, inkjet, transferencia, papelgel*