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DIGITAL REPRODUCTION TECHNIQUES APPLIED TO CONSERVE PAPER THEATERS: A CONTEMPORARY APPROACH TO THE PRESERVATION OF CULTURAL HERITAGE

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Abstract

Digital captures of originals and generating images are contemporary preservation strategies. Creating ad hoc prints is an advantageous solution for chromatic reintegration of modern and contemporary artefacts due to their versatility and durability. Printing likewise serves to produce facsimiles with the objective of reserving the original and, therefore, assuring its preservation. The University of Granada (Spain), in an attempt to better understand contemporary prints, has delved into the behaviour of laser ink prints on cotton paper by means of accelerated ageing. The results gleaned from the digital conservation techniques were applied to a Children's Theater to generate both a physical and digital facsimile. The paper game was designed in the first half of the 20th century by Industrias Gráficas Seix & Barral Hermanos and is currently housed in Granada in the Manuel de Falla Archives. The restoration of other similar artefacts in Spain's National Library has likewise rendered it possible to correlate traditional physical and chromatic reintegration procedures with new methods to identify criteria better adapted to them.

Keywords: *Paper theatres; Preservation; Contemporary prints; Generating facsimiles*

Introduction

The emergence of new digital technologies and their advantages over analogue procedures has led to their application in many fields and disciplines. An example is resorting to digitisation for the physical and chromatic reintegration of artefacts of cultural heritage and, as a method of preventive conservation, to produce facsimiles. Delving into the options offered by these technologies in restoring certain types of objects, although subject to debate when compared to traditional treatments serving to attain the physical reintegration of the media and manual chromatic finishes, are proving to be very appropriate and in line with the semantic and material conservation of artefacts.

Recent years have seen a surge of interest among researchers to resort to *ad hoc* impressions for chromatic reintegration. Worth highlighting is the study by *T.K. McClintock et al.* [1] describing the chromatic reintegrating of graphics and texts of a globe by means of digital

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inkjet printing. Another similar article on laser printing delves into the means of restoring an advertising poster [2] or the printed chromatic reintegration of a 19th century lithograph [3]. Yet the methods studied and put into practice so far have not resorted to direct printing for the chromatic reintegration of an original but have required intermediate media serving as a base for the image.

The current study stems from research developed for the restoration of a children's paper theatre (*El Teatro de los Niños*) manufactured during the first half of the 20th century by *Industrias Gráficas Seix & Barral Hermanos* and housed in the Archives of the Manuel de Falla Foundation (Granada, Spain). Specifically, the task consisted of replacing missing parts of both its medium and certain of its images with colour impressions (Fig. 1).

Fig. 1. General view of the *Children's Theater* (Model E) with scenery linked to the second act of the play *Sancho Panza, Governor*

Paper theatres were introduced in Spain through Catalonia during the last decades of the 19th century and throughout the first half of the 20th century by *Paluzie* printers and the *Industrias Gráficas Seix & Barral Hermanos* publishing house. One of the most popular and colourful was *The Children's Theater* (1915), marketed by *Seix & Barral* with a proscenium arch and curtains prepared for assembly. Between 1915 and 1953 they produced up to ten different models. The games were complemented by the scripts of 23 plays compatible with all the models. Each set was offered for sale in an envelope-folder containing personages to cut out, two booklets with the scripts of the play and several scenarios for each act. The envelope-folders themselves formed part of the work, as from then on one could cut out entry tickets and a poster announcing the day of the performance. The set has since evolved from being a didactic game to becoming an asset of cultural heritage that must be preserved and conserved.

The game was designed using a variety of materials, notably industrial paper, glassine paper, laminated cardboard, linen, metal and adhesive. This section focuses on both the paper theatre and the booklet containing the script.

- The Theater. The structure of the main stage consists of laminated cardboard serving as the basis of chromolithographs printed on industrial paper. The two parts of the proscenium are attached to the set by two metal hinges. The curtain and the front curtain are of the same materials as the theatre. The wing drapes and curtains consist of chromolithographs set on a type of cardboard with a lower grammage than the others. Finally, the curtains are of linen and hung from a metal rail.

- The ***Sancho Panza, Governor script.*** The envelope-folder containing the script was printed on industrial paper with a satin finish. The booklets containing the scripts were printed by offset on industrial fine grammage paper. The sets of both acts and the sheet with the personages consist of chromolithographs on cardboard of the same grammage as those of the wing and wing drapes. The final decorations of both acts (nos. 245 and 248) also feature glassine paper.

The restoration of this model of *The Children's Theater* has served to question, debate, investigate and analyse the advantages of digital reproduction techniques. This method in fact serves as an alternative to the more traditional conservation methods applied to these objects. Moreover, this restoration enabled establishing contacts with the collection of paper theatres housed in the National Library of Spain which has led to a conservation campaign focusing on them. Their study is thus one of the goals of this project.

Experimental part

Prior to the restoration it was necessary to explore the stability of the ink. This required defining the printing technique and its materials (ink and medium). Likewise, a series of tests were chosen applicable to this research based on UNE-EN ISO standards, notably to test the aging of inks printed on cellulosic media.

Materials

Based on the conclusions gleaned from a bibliographic and organoleptic review of options available on the market, our selection was narrowed down to *Canon imagePRESS T01* ink on *Somerset Book® Soft White* paper. This ink stems from pigments, that is, solid-coloured substances suspended in a liquid. T01 inks are designed to offer a wide range of colours, good saturation and resistance to fading, features that we have attempted to confirm here. The choice of the professional printing technique, although not applied to artistic production, is borne out by another research [1-5].

Somerset Book® Soft White paper was selected for its positive results in other studies [6-8]. This high-quality medium is acid-free and during its production is treated with calcium carbonate providing it with an alkaline reserve. It consists of cotton pulps which give it a soft and slightly satiny texture. It serves a variety of artistic disciplines such as printing, engraving and watercolour due to its resistance and ability to faithfully reproduce colours and details. Its cotton fibres are resistant and durable. In addition, one of its distinctive characteristics is its ability to uniformly absorb and retain ink, hence ideal for this type of restoration.

Methods

The design of the method for the study was structured in four different stages: analyses of the printed object, sample preparation, carrying out standardized studies and physical characterization prior and subsequent to each test.

This study recreates conditions of humidity, temperature and lighting similar to those suffered by a real object by subjecting the samples to five physicochemical tests: ink adhesion, resistance to relative humidity, resistance to immersion in water, aging in climatic chamber and aging with dry heat. The levels of humidity, temperature and light radiation were controlled at all times to ensure a correct improvement. The recreation of deterioration factors is intended to anticipate future changes that may occur under normal conditions. Administering these types of tests in the laboratory shortens the periods of time required to observe degradations.

Characterizing the samples upon completion of the tests allowed comparing the results with the initial reference values which then served to offer solutions to problems deriving from their conservation and restoration. The values established for these characterizations are as follows: weight and thickness, colour, pH and surface observations with an optical microscope.

Preparing the samples required generating digital printouts of primary colours and black which were cut into 25×25mm squares. Those intended for aging tests through exposure to light radiation measured 40×40mm. These were labelled with a code consisting of an acronym of the test name followed by the type of printing. An example of this code is ACC-LA-YE corresponding to an aging test in a climatic chamber of a yellow laser print. Replicas retained as references and control samples were retained in airtight conditions. It was likewise necessary to assure stable conditions of humidity and temperature at 25ºC and 30% RH.

Ink adhesion test

This test aimed to analyse the interaction between the laser ink and the medium by analysing its capacity of adhesion. This mechanical process combined heat and pressure after the toner penetrated into the porous system of the paper wrapping itself on the fibres. A lack of adhesion can lead to detachment or transfer by contact to other media. The absence of a standardized test to measure the degree of ink adhesion to paper required adapting to other means [9].

The test was carried out by means of a series of parallel equidistant cuts (1.0mm) followed by similar perpendicular cuts who's spacing was determined by the thickness of the samples. The cuts were then cleaned with a bristle brush before applying and swiftly removing a transparent adhesive tape. Evaluating this test required comparing the surface of the samples with those of the reference table [9].

Resistance to environmental humidity

High levels of humidity provoke the deterioration of cultural assets, especially graphic works. It is thus of essence to determine the effects of humidity on printed works as well as establish the appropriate relative humidity parameters required for their conservation and restoration treatments [10]. Printed inks, when facing relatively high humidity, may bleed or transfer to an adjacent medium. Among the materials serving to carry out these tests are the samples cited above, blotting paper (100% cellulose, acid-free) and tweezers. The treatment also requires the following equipment: BELO illuminated Low Pressure Table chamber, a BURG Humidifier and a GESA E 08 00 digital thermo-hygrometer.

The test followed the guidelines described by international regulations [11]. This meant placing the samples next to the thermo-hygrometer inside the humidification chamber before closing it and maintaining a relative humidity of 65%. The task included applying humidity during timeframes of 0, 6, 12, 24 and 48h. Thus, at the end of each interval, the samples were extracted with tweezers and dried by air on blotting paper.

Resistance to Water Immersion

As printed works risk water damage during restoration or due to accidents and catastrophes, it is necessary to determine their behaviour when they suffer from these conditions. The materials required for these tests consist of the prepared samples, distilled water, a bucket, tweezers and blotting paper (100% cellulose, acid-free). The water was purified by the Milli-Q system. The bucket was then filled until the samples were completely submerged. These were placed with their reverse facing inward and left underwater during 30-minute intervals. At the end of each interval, they were removed with tweezers and placed on blotting paper to dry air. The evaluations were carried out once the samples were completely dry [12].

Aging in a Climatic Chamber

The samples for this test were subjected to different types of deterioration by simulating adverse temperature, relative humidity and light radiation [13]. The method has been put to use by the research group on different occasions, for example for the study the behaviour of arabic gum in graphic works [11], the degradation of indigo blue [14], the stability of the colours of ink injection printouts [7] and the protective varnishes in graphic works [8].

This test thus resorted to the prepared samples, blotting paper (100% cellulose, acid-free) and tweezers. Accelerated aging was carried out in a Solarbox 3000Erh chamber equipped with a xenon range of 250-1100W/m2, 190-800nm region and S208/S408 indoor filter. The conditions of control were applied with the Xen43 program. In accordance with the UNE Standards [15], the samples were placed in the chamber and subjected to the following aging cycle parameters:

temperature 80ºC, relative humidity 65% and UV radiation 550W/m^2 for 144 hours. The samples were then removed from the chamber with tweezers and placed on blotting paper. They were only evaluated after attaining room temperature.

Dry Heat Aging

The materials serving for this test were the samples prepared, tweezers and blotting paper (100% cellulose, acid-free). The equipment, in turn, consisted of a Beschikung-Loading Oven Modell 100-800 Memmert ULE 600 and a desiccator. Following the instructions described by UNE-EN ISO 57092-1 [16], the test consisted of placing the samples on blotting paper in the oven at a temperature of 105º for a single aging span of 144 hours. Once completed, the samples were removed with tweezers, placed in a desiccator for 30 minutes and only evaluated after drying.

Aging through Exposure to Laboratory Light

Print aging by means of direct light is a technique adopted in previous research [17] by resorting to a CIE illuminant simulator, incandescent lamps and fluorescent lamps. The novelty of this technique lies in the fact that the lamp's spectrum is very similar to sunlight. The test resorted to a PRO-LINE Gravitia Pro 270e LEP EU model marketed by the Dutch company Gravitia Profesional Lighting. It is a type of LEP (Light Emitting Plasma) lamp of the LUXIM model 41.02 with an intensity of 2.75-11.1A and an input of 290V.

The lamp was placed 20cm above the samples for 144 hours. Half received direct exposure while the other half were covered with black cardboard. This allowed us to compare the two so as to identify the potential chromatic changes. The methods serving to evaluate the effects of the tests described above are listed below. These tests were administered before and after each physicochemical test:

Size, weight and thickness

This consisted of measuring potential variations among both the length, width and thickness of the samples so as to determine the changes to the fibres either due to swelling or drying. Weight variations can stem either from the evaporation of compounds (decrease) as well as by absorption of fibres (increase).

Measurements of their length and width were taken with a millimetre precision ruler. Weighing, in turn, resorted to a milligram precision scale. Using tweezers to manipulate the samples avoided contamination. Finally, thickness was measured in microns by means of a Mitutoyo No. 2046F gauge.

Colour

Recording the colour of a sample requires three measurements at different points by means of both included and excluded specular reflection, a 3mm aperture mask and 0% UV [19]. The CIE L*a*b* model allows an objective description of colour based on the L* (luminosity), a* (red, green) and b* (yellow, blue) coordinates. This model likewise works with the C* (chroma) value, which directly relates to colour saturation. As higher C* values signal greater saturation, the lower the values, the greater the probability of achromatism. This also, on the other hand, works with value h* (tone), which is responsible for indicating the category to which a colour belongs by assigning it a name. The value is displayed in degrees.

This was undertaken with a Minolta CM-2600D portable spectrophotometer (parameters: measurement area/MAV illumination 3mm, observer 10º; illuminant D65). The values were automatically saved in the equipment for later comparative analyses. To calculate the difference of the global ΔE* value, this study resorted to the following equation:

$$\Delta E^*_{ab} = [(L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2]^{1/2} \quad (1)$$

The results of the global colorimetric differences identified the samples affected by colour variation. A ΔE*ab range from 2.3 to 3 can be considered hardly noticeable, that is, barely perceptible between two intensity levels perceived after a sensory stimulus. Printing standards are regulated by addressing tolerance values for ΔE*ab [18-20].

Measuring Brightness

This test to measure the brightness (UB) of the samples prior and subsequent to the physical-chemical tests is based on the ability of their surfaces to reflect light and the angle at which it is reflected. A bright surface reflects light in a specular manner. A matte finish, in turn, yields a diffuse light. The test was carried out with a Konica Minolta Multigloss MG-268 portable meter (measuring geometry 20º, 60º and 85º; measurement area 20º: 10×10mm; 60º: 9×15mm; 85º: 5×38mm; repeatability 0.00 ~ 99.9UB: 0.2UB) and regulated by the *UNE-EN ISO 2813:2014 Standard*, according to which an 85º measurement angle was selected in the glossmeter prior to undertaking three measurements yielding maximum, minimum and mean values [20].

Determining the pH

The test was applied to the reverse of the samples so as to determine whether a potential ink pH variation had an effect on the medium given that the possibility of increased acidity of the inks or an influence on the medium which would rule out their use in the restoration processes. The pH test was applied with a portable pH Crison pH Meter GLP21 with a surface electrode (range 0.00~14.00; resolution 0.01; precision ±0.01). The materials consisted of the samples before and after each physical-chemical test, deionized water (pH 5.5-7.5; conductivity <1.25S/cm) and blotting paper (100% cellulose, acid-free). Those yielding values greater than 0.5 were deemed to be variations of pH. The pH measurement procedure was applied by placing a drop of distilled water on the surface of the printed sample (recto) accompanied by setting the electrode of the pH meter on it continuously until the measurement stabilized.

Optical Microscope Observations

The objective of this test was to observe if the amplification of the image on the surface of the samples reveals alterations to the layer of colour, notably bleeding, changes in texture or lack of homogeneity. The test was carried out with a Nikon DSFi2 optical microscope (0.8 to 8.0× zoom) with episcopic illumination system.

Results and discussion

The alterations identified in the samples were analysed from the standpoint of physical parameter data (dimensions, weight, thickness, colour, brightness, pH and optical microscope observations).

Results of the Ink Adhesion Test (IAT)

All colours fall into category 4 of the reference table [6] where the prints detach into large bands along the edges of the incisions and where certain squares completely separated proving their poor adherence to the medium (Fig. 2). The area affected by the trellis is greater than 35% but less than 65%. Their thickness, subsequent to the test likewise suffered a decrease of 0.01mm.

Fig. 2. View of the samples serving to determine the degree of ink adhesion

Results of the Resistance to Environmental Humidity Test (EH)

Environmental humidity did not affect the physicochemical parameters of dimension, weight and thickness. The analysis of the data reveals changes in the values of both luminosity (L*), chroma (C*) and tone angle (h*) (Table 1). Therefore, environmental humidity has only minimally influenced the colour of the black EH-LA-BL samples. These printed samples, according to standards [17] and considering the ΔE*ab values, are excellent (ΔE*ab 1) and good (ΔE*ab 1-2).

Table 1. Differences in luminosity, chroma and tone stemming from the EH test

	ΔL^*_{10}	$\Delta C^*_{ab,10}$	$\Delta h^*_{ab,10}$	ΔE*00
EH-LA-YE	0.03	0.05	0.07	0.05
EH-LA-CY	0.03	0.19	-0.09	0.08
EH-LA-MA	0.26	-0.42	0.04	0.28
EH-LA-NE	1.36	-0.08	-10.61	**1.14**

The observations of the values of brightness levels gleaned from the test, all below 10UB, indicate that all the samples bear a matte finish.

The pH measurements (Fig. 3) suggest that the primary colours maintain values that vary less than or equal to 0.5, thus remaining within the neutral range indicating there is no need to take them into consideration. The sample printed in black with a pH variation of more than 0.5 transcends from neutral to basic. Thus, in general terms, it is possible to affirm that yellow, cyan and magenta are stable as they do not reveal substantial variations of any of their physical-chemical parameters. Black, in turn, is the most affected by the test due to its colorimetric and pH variations.

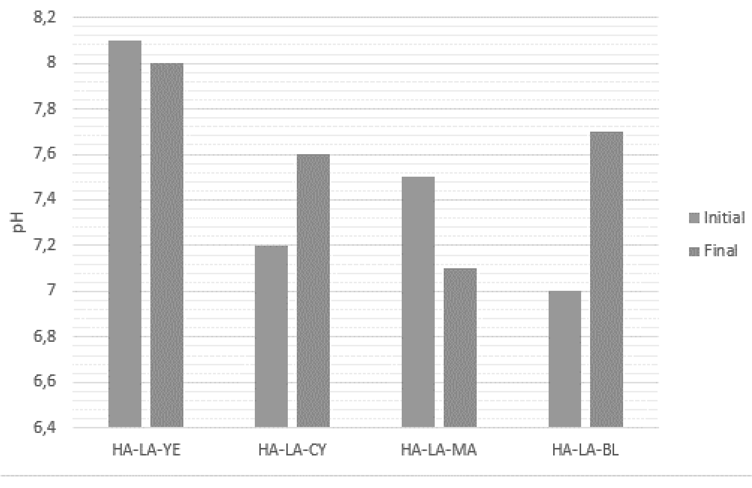

Fig. 3. Results of the pH levels of samples subjected to the Environmental Humidity test (EMP_{pH} ± 0.5)

Results of the Resistance to Immersion in Water Test (IW)

The results reveal that the samples underwent no changes in dimension and weight. Moreover, their variations fall within the minimum margin of error. On the other hand, measurements of their thickness indicate increases among all colours. This is perhaps due to a swelling of the cotton fibres due to their capacity to absorb water. It is for this reason that it is possible to state that immersion in water for 180 minutes increases thickness. The colour parameter was only affected in the black sample after 30 minutes of immersion (Table 2).

Table 2. Differences of the black luminosity, chroma and tone gleaned from the IW test

	ΔL^*_{10}	$\Delta C^*_{ab,10}$	$\Delta h^*_{ab,10}$	ΔE00
IW-LA-BL-01	-2.65	0.03	2.65	**2.08**
IW-LA-BL-02	-2.13	-0.11	2.14	**1.68**
IW-LA-BL-03	-2.23	0.11	2.23	**1.75**
IW-LA-BL-04	-2.46	0.01	2.47	**1.95**
IW-LA-BL-05	-2.22	0.08	2.25	**1.77**
IW-LA-BL-06	-2.26	0.02	2.30	**1.83**

The values obtained from the brightness measurements reveal a downward trend among all the samples (Fig. 4). As in the case of resistance to environmental humidity, all are characterized as matte as their levels are less than 10UB.

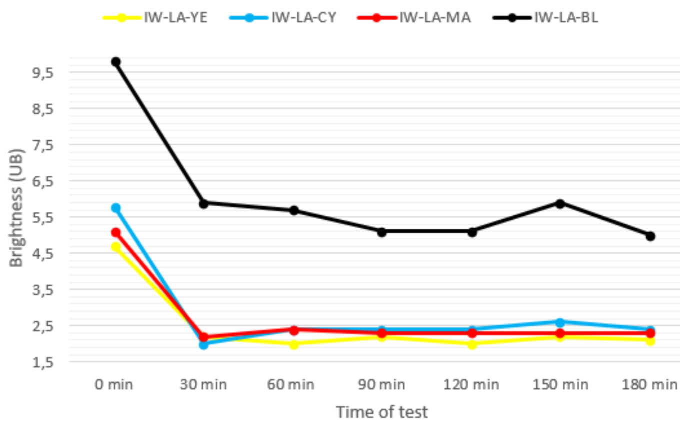

Fig. 4. Line graph depicting the results of the bright study of the samples subjected to the IW test

The yellow samples reveal a pH similar their original values which is why there is no effect on the print subjected to the immersion in water test for 180 minutes. The cyan, magenta and black prints, in turn, reveal variations of pH after this test ranging from neutral to basic (Fig. 5).

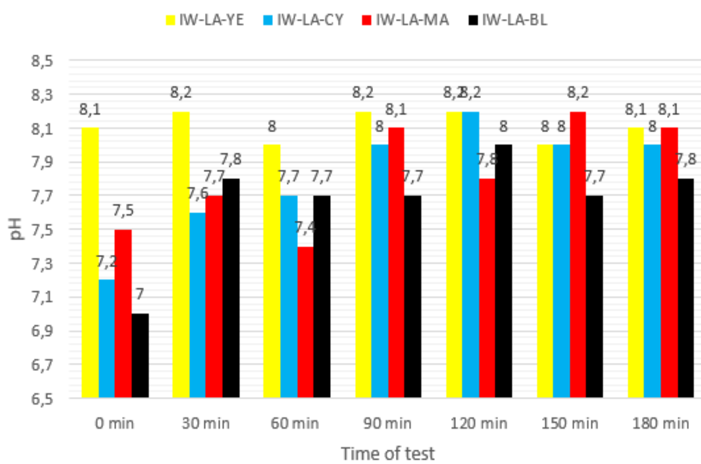

Fig. 5. Results of the pH measurements of the sample subjected to the Resistance to Immersion in Water test (EMPpH ±0.5)

What is noteworthy when summarizing the results of this test is that all cases reveal certain variations of their properties, notably fibre expansion, loss of brightness or increase of pH. Moreover, of all the colours, black, once again, reveals the worst results.

Results of the Aging in a Climatic Chamber Test (ACC)

None of the samples were affected by a variation of size or thickness. The results, in fact, suggest a considerable decrease in pH values and a slight decrease in weight.

Yellow and magenta are the most affected by the colorimetric test (Table 3). Aging in a climatic chamber for 144 hours yielded a minimal increase of tone. Therefore, although humidity, temperature and light bear no chromatic effects on cyan and black, they do alter yellow and magenta.

Table 3. Differences in luminosity, chroma and tone gleaned from the ACC test

	ΔL^*_{10}	$\Delta C^*_{ab,10}$	$\Delta h^*_{ab,10}$	ΔE00
ACC-LA-YE	-0.53	11.40	-1.15	**3.12**
ACC-LA-CY	0.01	0.91	2.04	0.82
ACC-LA-MA	-2.62	3.80	-0.50	**2.76**
ACC-LA-BL	-0.24	0.17	-31.76	0.90

Likewise, all colours reveal a decrease of brightness situating them in matte values (Fig. 6 and Table 4). Yellow and magenta are the most affected by aging while cyan and black remain stable.

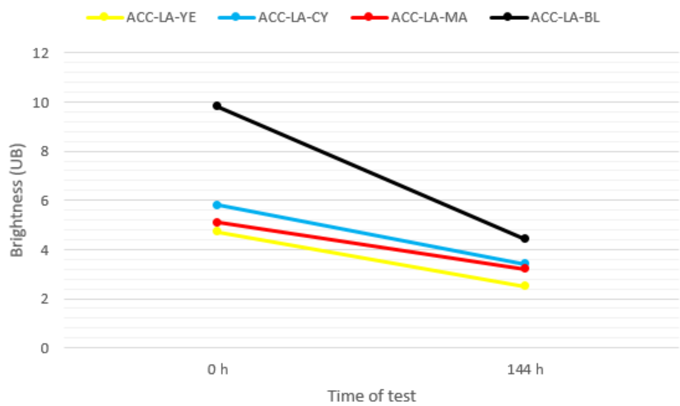

Fig. 6. Results of the brightness study of the samples subjected to the aging test in a climatic chamber

Table 4. Difference in brightness of the samples with respect to their original measurements gleaned from the ACC test

Time (h)			**144**	
Color	**YE**	**CY**	**MA**	**BL**
Brightness (UB)	2.5	3.4	5.1	4.4
ΔUB	-2.2	-2.4	-1.9	-5.4

Yellow and magenta reveal changes of pH from basic to neutral which confirms that aging these samples in a climatic chamber test for 144 hours affects their prints. Cyan and black, in turn, suffered no pH variations during the test.

Results of the Dry Heat Aging Test (DHA)

Although the values of size and thickness remained stable after this aging, the samples do reveal a slight decrease in weight. With the exception of black, all colours suffered a difference in their colorimetric values with ΔE*00 surpassing 1 (Table 5).

The values obtained from measuring brightness levels point to a decrease in all the samples. As in all the previous physical-chemical tests, the samples can continue to be characterized as matte as they all fall below 10 UB. The findings also reveal great variations in the brightness of black yet less among the other colours. What is equally notable is that they are not perceptible to the naked eye and always fall within the matte range.

Table 5. Differences in luminosity, chroma and tone gleaned from the DHA test

	ΔL^*_{10}	$\Delta C^*_{ab,10}$	$\Delta h^*_{ab,10}$	ΔE00
DHA-LA-YE	1.94	-7.05	0.21	**2.09**
DHA-LA-CY	0.36	1.22	5.90	**2.28**
DHA-LA-MA	0.94	-2.09	2.55	**1.51**
DHA-LA-BL	0.87	-0.27	11.59	0.8

The results of the pH measurements after 144 hours of testing demonstrate that yellow, cyan and magenta remain basic. Thus, these general findings suggest this to be the test bearing the greatest effect on the samples with black being the most stable.

Results of the Aging by means of Light Radiation test (ALR)

The results of direct exposure of the samples over a span of 144 hours to light radiation indicate that this test does not alter their size, weight, or thickness. The L*, C* and h* values confirm that the samples after 144 hours (except for the ALR-LA-BL) yield a ΔE00 greater than 1 (Table 6) implying chromatic variations among the yellow, cyan and magenta samples.

Table 6. Differences in luminosity, chroma and tone obtained from the ALR test

	ΔL^*_{10}	$\Delta C^*_{ab,10}$	$\Delta h^*_{ab,10}$	ΔE00
ALR-LA-YE	1.03	6.58	-0.66	**1.87**
ALR-LA-CY	2.14	-0.01	2.25	**1.99**
ALR-LA-MA	0.83	0.00	1.28	**0.99**
ALR-LA-BL	0.35	-0.02	-6.16	0.35

Aging subsequent to 144 hours of exposure to dry heat produced a slight decrease of the tone of the colours. Therefore, the direct luminosity parameter affects yellow, cyan and magenta, but not black. The results also suggest variations in brightness of black lower than those of the other colours. Equally noteworthy is that they are not perceptible to the eye and always fall within matte ranges.

The pH values signal that yellow and magenta were affected by the test, the first passing from a basic to neutral value and the second from basic to acidic. By contrast, the pH of cyan and black converted from neutral to basic upon exposure to light. The test thus proves that the black samples are the least affected to aging by means of light radiation (Fig. 7).

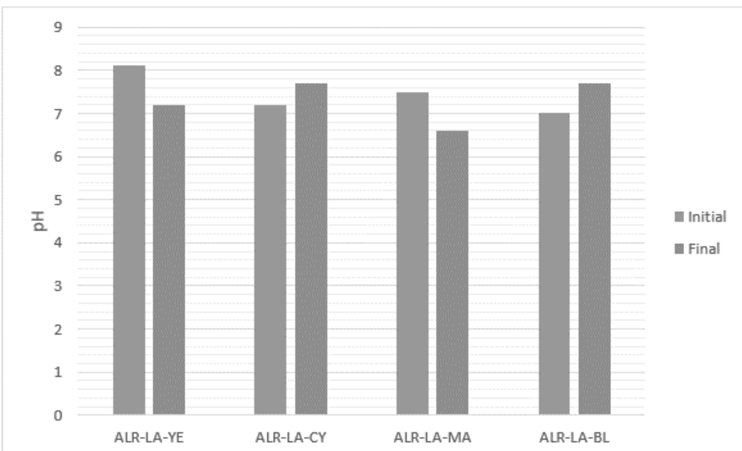

Fig. 7. Results of the pH measurements of the samples subjected to the ALR test (EMPpH ±0.5)

The comprehensive analysis of the results shows that cyan stands out as the most stable color (Table 7), demonstrating resilience against deterioration, including aging in a climatic chamber. The only aspects affected were its brightness and pH.

Table 7. Comparison and summary of the results of the different tests on the cyan samples

Printed ink	**Cyan**				
Results					
Tests/Characteristics	**EH**	**IW**	**ACC**	**DHA**	**ALR**
Size	No changes	No changes	No changes	No changes	No changes
Weight	No changes	No changes	Slight decrease	Slight decrease	No changes
Thickness	No changes	Slight increase	No changes	No changes	No changes
Colour	Yellowing	No changes	No changes	Tone increase	Saturation
Brightness	No changes	Slight decrease	Slight decrease	Slight decrease	Slight decrease
pH	No changes	Increase	No changes	No changes	Increase

Black of all the colours reveals the most changes in the aging tests, mainly in what concerns brightness and pH which increased throughout all the tests except dry heat (Table 8).

Table 8. Comparison and summary of the results of the different tests on the black samples

Printed ink	**Black**				
Results					
Tests/Characteristics	**EH**	**IW**	**ACC**	**DHA**	**ALR**
Size	No changes	No changes	No changes	No changes	No changes
Weight	No changes	No changes	Slight decrease	Slight decrease	No changes
Thickness	No changes	Slight increase	No changes	No changes	No changes
Colour	No changes	No changes	No changes	No changes	No changes
Brightness	No changes	Slight decrease	Slight decrease	Decrease	Decrease
pH	Increase	Increase	No changes	Increase	Increase

Yellow and magenta in the end were the most sensitive colours. Alteration of their hue and brightness when printed affects their aesthetic appearance. Yellow reveals a decrease in pH in the aging tests and a colorimetric change in all tests except ambient humidity (Table 9). Magenta is likewise affected after exposure to water and aging as noted through their variations of colour and brightness. These changes, evident through visual examination, pose a risk to their conservation (Table 10).

Table 9. Comparison and summary of the results of the tests on the yellow samples

Printed ink	**Yellow**				
Results					
Tests/ Characteristics	**EH**	**IW**	**ACC**	**DHA**	**ALR**
Size	No changes	No changes	No changes	No changes	No changes
Weight	No changes	No changes	Slight decrease	Slight decrease	No changes
Thickness	No changes	Slight increase	No changes	No changes	No changes
Colour	No changes	Yellowing	Saturation	Yellowing	Saturation
Brightness	No changes	Slight decrease	Slight decrease	Slight decrease	Slight decrease
pH	No changes	No changes	Decrease	Decrease	Decrease

Table 10. Comparison and summary of the results of the tests on the magenta samples

Printed ink	**Magenta**				
Results					
Tests/ Characteristics	**EH**	**IW**	**ACC**	**DHA**	**ALR**
Size	No changes	No changes	No changes	No changes	No changes
Weight	No changes	No changes	Slight decrease	Slight decrease	No changes
Thickness	No changes	Slight increase	No changes	No changes	No changes
Colour	No changes	No changes	Saturation	Yellowing	Increase tone
Brightness	No changes	Slight decrease	Slight decrease	Slight decrease	Slight decrease
pH	No changes	Increase	Decrease	No changes	Increase

The Children's Theater. Applying digital printing techniques

Prior to applying the digital reproduction techniques, our work focused on the stage and the script so as to diagnosis their state of conservation. Photographs were taken with a Fujifilm X-A2 camera throughout each of the steps of the intervention.

Both *The Children's Theater* and the script were in good condition in spite of signs of wear due to their use of a children's game. The prints bore a patina provoked by wear and the passage of time. Small scratches causing an occasional loss of the print were likewise observed.

The intervention consisted of mechanical cleaning with erasers and chemicals with a sponge to eliminate surface filth. This was followed by consolidation of the decohesions. In the cases of impression loss, grafts were applied with Japanese paper (Fig. 8) prior by a chromatic reintegration with watercolours. Consolidation to the envelope-folder was administered with Type B gelatine (1.5%) and direct lamination with the same adhesive (but at 2%) with white Nao paper (3.6g). The technique was also applied to the breaks and tears.

Fig. 8. Grafting to complete the gaps of the main stage of the theatre

The project resorted to digital printed chromatic reintegration to restore the incomplete personages of the play based on the results of the empirical-analytical accelerated aging test. To carry out the digital printing of the four missing personages it was necessary to obtain a reference image of the missing personages from the National Library of Spain, available in digital form through the Hispanic Digital Library (BDH).

The image was then treated with *Adobe Photoshop CC 2021* software and its colour profile adjusted to be embedded in *Adobe RGB 1998*. The subsequent printing of the digital file was in line with the materials studied in the previous empirical analysis, that is, digital laser printing with *Canon imagePRESS T01* ink on *Somerset Book® Soft White Paper 115g*. The missing parts of the printouts of the personages of the play were then substituted by cut out grafts which were attached by means of flanges with adhesive methylcellulose and reinforced with white Nao paper (Fig. 9).

The decision to create a digital facsimile in the framework was justified given that it not only represents a preventive action but will serve to disseminate the object. This required capturing its different elements at high resolution (400dpi) with an EPSON Expression 10000 XL scanner.

Fig. 9. The personages called "Pueblo" of the play before and after their printed chromatic reintegration

Physical facsimiles can be broken down into photographic and high-quality facsimiles or pseudo-originals. The first consists of a life-size photographic reproduction whereas the latter imitate the structure, materials and even the deterioration. It is extremely vital to establish the difference between a digitized document where priority is placed on content (and not its characteristics) and a digital facsimile requiring an adequate management of the colours.

A printed facsimile of the game was thus generated from the scans of the digital facsimile (Fig. 10). Creating the physical copy involved sharing intervention criteria and results. The reproduction faithfully considered the different materials (chromolithography, glassine and industrial papers, fabric, cardboard and metal) of the original. After scanning, the files were treated with *Adobe Photoshop CC 2021* software so as to adjust their colour and to select and eliminate the background with the "lasso" tool. Finally, tests were carried out at different levels of exposure to determine which was optimal for printing.

The facsimile of the stage, the curtain and the open drapes were printed on *140g Tintoretto paper* prior to fixing them to 2mm grey cardboard. The pieces were cut out with an industrial blade die-cutting machine and by hand (Fig. 11).

The curtains and the metal rod were reproduced with the same materials as the originals. The new rail thus consisted of a 2mm iron wire and the new curtains were made of linen with the sewing imitating the original pattern imitating which, depending on the area, was stitched, hemmed, or basted.

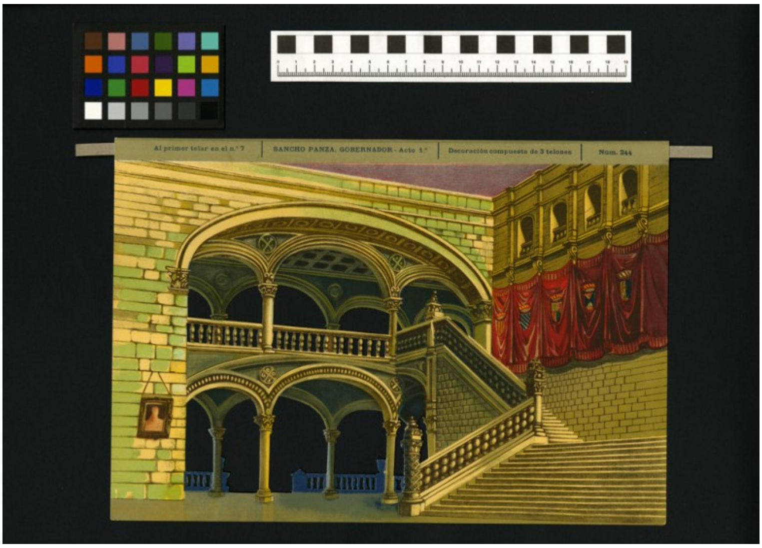

Fig. 10. Digital facsimile of décor no. 244

Fig. 11. View of the complete facsimile of *The Children´s Theater* and the play *Sancho Panza, Gobernador*.

The envelope-folder was printed with a plotter on 140g paper. The decors of the play, in turn, were printed on 200g offset paper.

The research carried out indicated that the personages were sold uncropped. This raised a relevant question: should the personages be printed and cut out, or should they be identical to the original sheet? When reproducing them, should the facsimile only correspond to the game housed in the Manuel de Falla Archives? Furthermore, should original and restored personages be combined among with facsimiles? However, as the intention was the creation a facsimile of the game itself as a cultural asset, we opted to reproduce the complete sheet of personages provided by the National Library of Spain. Likewise, we reproduced some of the personage cut-outs adhering to the laminated cardboard strip to illustrate their method of assembly.

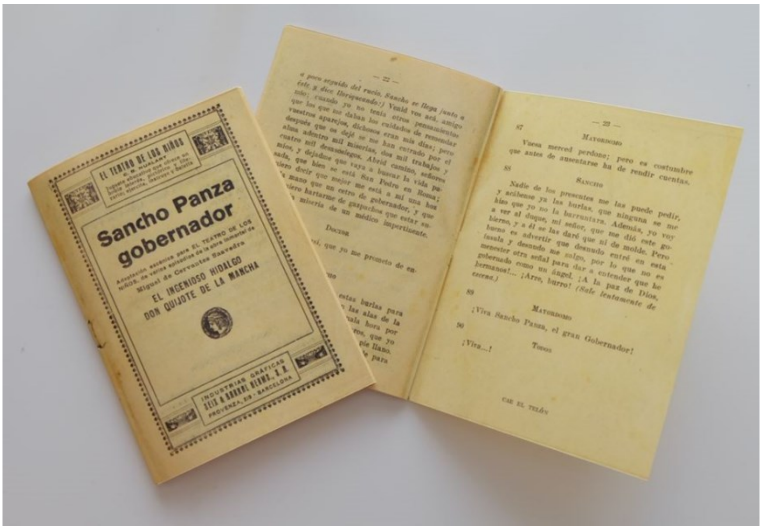

Fig. 12. Facsimile of the booklets of the script of the play *Sancho Panza, Gobernador*

As in cases of digital chromatic printed reintegration, the printing of the digital file of the personages after treated was carried out with a digital laser printer with *Canon imagePRESS T01* ink on *Somerset Book® Soft White Paper 115g.* The booklets of the *Sancho Panza, Gobernador* play, in turn, were printed on 70g offset paper (Fig. 12).

Conclusions

The study of the samples of each of the colours through tests correlated to the analyses of each of the physical-chemical parameters serve to gain evidence to the factors that have a direct effect on the properties of the inks and which can potentially deteriorate them. Among those that directly alter black is water either in the form of ambient humidity or in a liquid state (immersion). Temperature (part of the aging in the climatic chamber and dry heat tests) mainly affected yellow and magenta in the climatic chamber and the colour and pH of the yellow, magenta and cyan (the latter to a lesser extent) samples in the dry heat test. Light radiation (present in the climatic chamber and through light radiation test) once again led to damage among the yellow, cyan and magenta samples in the climatic chamber. The test exposing the samples to direct light radiation had an influence on the pH of all colours.

It is possible to affirm that the most stable parameters of all the colours are size, weight and thickness. While those of colour and pH reveal substantial changes, it is brightness that is the most affected. All in all, the prints produced with laser technology present a medium/high degree of stability under simulated aging conditions. These results can only be verified by technique-ink-media combinations as each technique, ink and medium of today's market reveal different characteristics and compositions.

Resorting to printing for chromatic reintegration processes was essential to complete the restoration of the game as it gave back, as expected, legibility to the work. This type of reintegration also permits differentiating between the original work and the additions. Both the treatment carried out by the digital file, as well as the choice of materials and techniques, as demonstrated by the results of this empirical-analytical study, are appropriate due to the minimal chromatic variation between the original and added parts. It is noteworthy that the intervention, which is completely reversible, can be discerned from the original through visualization or image capture techniques with transmitted light or with different wavelengths. Similarly, the study reveals that laser printing with *Canon imagePRESS Toner T01* on *Somerset Book® Soft White* paper is suitable for the chromatic reintegration of graphic and written works of similar grammage.

The digital facsimile produced here ensures the durability of the components of *The Children's Theater* as well as the script of the play entitled *Sancho Panza, Governor* as it can serve to produce future reproductions if the original were ever to be destroyed. The quality of the scanned high resolution TIFF files can also serve to disseminate and print physical facsimiles. However, their digital files can suffer from aging and must be updated periodically.

Producing a physical facsimile was also one of the original objectives of the study. The task led to a debate within the team as to what materials to use, specifically the choice between specialized conservation materials or those bearing similarities to the original. Given that the main purpose of a facsimile is to preserve the original, as well as for it to serve as a didactic element for dissemination to the public, we opted to not use conservation materials but those used to manufacture the original game. It is due to this choice that *Somerset Book® Soft White Paper* was rejected for the copy in spite of it serving for its reintegration. Thus, the choice of materials used to produce the facsimile was based on their nature, similarity and fidelity with respect to the original. Finally, the facsimile of *The Children's Theater* is fungible and can deteriorate through use. This avoids manipulating the original thus ensuring its conservation. Moreover, the digital files of the facsimile render it is possible to replace parts of it in the event of deterioration.

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