Methodology For Assessing The Technical Quality Of Museological Fineart Reproductions From Digital Photographic Archives. 2019. Thesis (Doctorate in Architecture and Urbanism)

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Abstract

Keywords: fineart, colorimetric, workflow, digital, photography, printing systems, color space, RAW

Abstract

In this thesis a methodology for the evaluation of the colorimetric and physical quality of photographic reproductions were elaborated and systematized, from professional captures in RAW format, output in high quality printing systems using materials of high permanence. This mode of reproduction, called Fineart printing, requires some important care so that its result has high fidelity compared to the final file prepared by the artist/photographer. In addition, other good practices adopted in the method developed here guarantee the museological quality of reproductions that comply with hereby established requirements. Color space for image acquisition, printing methods, measurement methodology, control strips with colorimetric target, targets, and colorimetric tolerances are part of this methodology. It is expected that its use will allow objective quality control and easy implementation in this important field of visual arts.

For more than a century, professional photographers have had full autonomy to capture their images and then participate in the process of reproducing the images made up to enlargement onto photographic paper/film, analogic process. When the processes of capturing, processing and reproducing photography went digital, artists/photographers continued to perform their photographic captures (and processing) completely autonomously from other professionals. However, when it comes time to print the images, they depend on professionals who adjust their files for the output processes. This causes uncertainty in the process and

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delegation of authorship by photographers, artists, gallery owners, and museums, and reinterpretation of the images by print providers. The lack of participation in the authors' output processes is due, notably, to market inertia with the division of tasks and the lack of a methodology that can support authors in the evaluation of printing services, which are, in general, outsourced.

File adjustment (with consequent reinterpretation of the image) is necessary in the case of printing books and other products printed in analog methods (offset, flexography, or gravure), because these methods use the CMYK color space, and the RGB to CMYK transformation involves specific knowledge of the printing process, usually not well known outside the field of this industry.

For Fineart museum photography printing, which is the scope of this work, the images prepared by the photographers are RGB files, and their appearance is within the decision domain of their authors. In this workflow, images that have been captured in RAW are "developed" on computers with appropriate and calibrated monitors. The photographer/artist, exercising his role as the protagonist of the artistic/technical production process, makes explicit his desire for the appearance of the image by adjusting exposure, white balance, tone curve, saturation, tonal curve adjustment, sharpness, and other visual characteristics of the image. At the end of this process, the resulting RGB file with ICC color profile is the artist/photographer's final file.

This file is passed on to reproduction service providers, and it is this file that indicates the author's intention and that it should be reproduced as faithfully (colorimetrically) as possible. However, it is quite common for photographers to hire professionals or send them to print providers to have their original images adjusted, with the justification that these professionals "would know how to prepare the images for Fineart printing". At this point, besides losing the autonomy of their own images, the artists/photographers decline the right to control the colorimetric appearance of their originals, opening the possibility for other professionals to modify their creation. Professionals involved in Fine Art reproduction services should do their best to honor the artist's original, avoiding editing its content. To control the final reproduction of the creator final files this thesis presents a full methodology allowing all stakeholders to certify the resemblance from the artist/photographer's final file and the fine art reproduction. The controlled reproduction is done strictly with the use of color management, museum materials, calibrated instruments, and proper methodology.

This work allows the authors to objectively evaluate the reproduction and minimizing the risks of having their final files edited. This methodology covers all the steps and tests performed that determined the formulation for evaluating reproductions of digital photographs in Fineart museum systems.

Workflow

Figure 1 shows the workflow of a Fineart image reproduction. Initially the image is captured in a professional camera, in RAW format. In this format the color information captured by the camera sensor is not yet fully defined. The image is then passed to a computer, where the image acquisition and editing process is done, which transforms it into an RGB file with a specific ICC profile, with all the pixels representing a certain colorimetric value. After retouching and approved, the image is considered a final file. The ICC color management is built into all computer operating systems and used by image editing and processing applications.

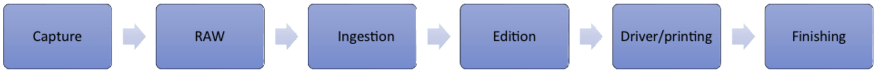

Figure 1. *The workflow of a Fineart image, from capture to exhibition-ready art*

The next step is printing this RGB file in a calibrated inkjet system on a high-permanence museum substrate with water base pigmented ink. The RGB values of the file are converted to ink values by means of the print driver, always seeking the highest color fidelity, i.e., the smallest color difference (DeltaE) between the pixels of the artist's final file and the result of the ink droplets printed on the substrate. The printing system must be able to print values closest to the values in the RGB photographic file. The printed photograph is at the end of the digital photography workflow, where usually finishing processes are necessary to allow the picture to be exhibited, using neutral and high permanence materials.

Color space for raw file ingestion and edition

Images in RAW data are usually ingested in applications such as CameraRAW or Adobe LightRoom with the presence of full sensor data. Such data is by nature richer than the RGB data resulting from the acquisition operation. It is typically 12 to 16 bits in size and does not yet have a colorimetric definition (demosaicing, white balance, scene color temperature, maximum black and tone curve operations have not yet been performed). This gives this data enormous flexibility in operations such as exposure changes, color changes, localized tonal adjustments, geometry adjustments and many others. At the end of the edits, the applications convert the data from the camera sensor into an RGB color space. It is a nondestructive process leaving the RAW untouched, that is why Adobe created a version of RAW named DNG, digital negative. Like an analogic negative film, it can be reproduced undefinedly without modifying the original.

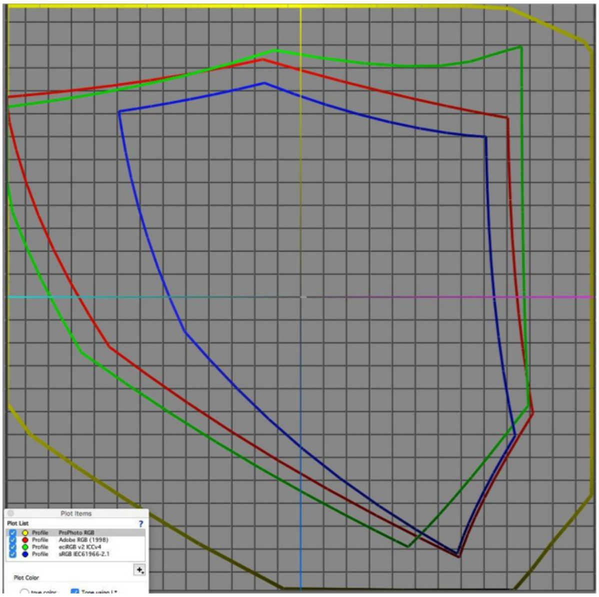

Figure 2. *Chart with the gamuts of the ProphotoRGB (yellow), ECI-RGB (green), AdobeRGB (red) and sRGB (blue) color spaces.*

Examples of color spaces usually adopted for the acquisition of camera images, when captured in RAW, have their gamuts illustrated above: ECI-RGB, sRGB, AdobeRGB, and ProPhotoRGB (Figure2). The ProPhotoRGB space with theoretical primaries outside the human visual field and therefore with an immense range, is used mostly as an internal conversion area of applications similar to Adobe CameraRaw (Photoshop) and LightRoom. In such applications, the use of a very large theoretical space gives scope for conversions and for image treatments prior to conversion to a definitive RGB space. Based on this study, it was suggested to adopt ECI-RGB as the coding space for printing.

The ProPhotoRGB gamut size is 2.5 million DeltaE; ECI-RGB, 1.3 million; AdobeRGB, 1.2 million; and sRGB, 800,000. To give you an idea of the difficulty of reproduction, with good color management it is possible to achieve up to 900,000 DeltaE on extremely smooth surface Fineart papers. This means that images captured in RAW with RGB acquisition and using very large RGB color space can have gamut compression rates of up to 50% of the space originally occupied by their colors.

The first color space studied was PRMG, that is an artificial CMYK color space. The origin of the PRMG color space was an attempt from ISO TC130 to generate a color space from a natural reflective colors collection that could be a significant representation of colors found in nature, and the set does not include fluorescent or emissive colors. The ISO committee felt that this collection could be transformed into a color space, which was suggested in ISO 12640-3 and later adopted by the ICC as the PRGM color space.

The attributes that make the PRMG a good candidate for workspace after ingestion of RAW photographic images lie in the fact that the PRMG has a very large gamut size, that it is representative of "real" world colors and that it has a format that is more compatible with the formats of printing equipment: "The shape of the PRMG is similar to that of a gamut of a printing system, thus quite different in shape from a reference display gamut" (BONNIER; GREEN; SERÍAT, 2007, p. 1).

As the gamut of PRMG does not comprehend all the gamuts of FineArt printing substrates and the transformations from RAW data to PRMG introduces some color distortions, probably because of artificial primaries, so it was discarded in favor other RGB color spaces. Several tests were done with AdobeRGB, ECI-RGB, and PRMG with ingestions from RAW data and the best performer was ECI-RGB.

Profile	adequacy of amplitude*	chromatic distortion	professional monitors	friendly to print	white point D50
PRMG	1º	4º	3º	1º	OK
ECI RGB	2º	1º	4º	2º	OK
AdobeRGB	3º	2º	1º	3º	No
ProPhotoRGB	5º	5º	5º	5º	OK
sRGB	4º	3º	2º	4º	No

* size and shape

Table 1. *Comparing working color spaces, with the natural choice of ECI-RGB. When tackled the monitor necessary to visualize and retouch images, AdobeRGB becomes the preferred choice.*

In Table1 is possible to see the assessment of colour spaces for ingestion and retouching where D50 white point, gamut format similar to printing gamut in format, availability of professional monitors in conformance with ISO 12646 within its gamut range and chromatic distortions in the ingestion process were taken in consideration.

A second assessment was made using a colorimetrically known image converted to DNG and ingested in the tested color spaces in Adobe Photoshop/Camera Raw. The precision of transformations is registered in Table 2.

Color Space	**ECI-RBG**	**AdobeRGB**	**ProPhoto**	**sRGB**	**PRMG**
Average ΔE00	1.59	1.89	1.91	2.80	1.19
Max ΔE00	3.01	2.92	2.91	5.95	4.24
95 Percentile	2.63	2.75	2.8	5.42	3.54

Table 2. *Assessment of performance for data acquired from RAW (ingestion) into several color spaces, average ΔE2000 difference, maximum, and 95 percentile error.*

According to what can be observed in Table 2, the profile that obtains the best average in conversion from RAW to “retouching/intermediary color space” is ECI-RGB, while the lowest maximum is given by ProPhotoRGB, and the lowest 95th percentile is that of ECI-RGB. Regarding the requirement of being “wide enough to contain the values captured by the sensors of the professional cameras in the market”, it can be inferred with this test that ECI-RGB, PRMG and ProPhotoRGB are adequate, with advantages for ECI-RGB, which is D50 based and was second in average of DeltaE2000 and third in maximum of DeltaE2000. Those are the reasons this study has chosen CEI-RGB to perform further developments in FineArt reproduction assessments.

Color inconstancy and metamerism of digital output printing inks

The next step of the study was to assess if the printing system in use was adopting colorants with adequate color consistency once the final reproductions are made to be seen in exhibition areas with very different illumination schemas.

The phenomenon of metamerism is what ensures that any reproduction process with subtractive synthesis can simulate any image, even if its inks do not have the same spectral reflectance as the reproduced objects. As far as this work is concerned, metamerism is important in analyzing Fineart’s exhibition spaces and the influence of illuminants other than those used in color management, the D50. In addition, it is also fundamental understanding color inconstancy. Color inconstancy is the change in appearance of a color when changing the illuminant under which it is observed. Less fickle colors are more appreciated for reproductions and by industry in general because products printed with these colors tend to maintain a relatively constant appearance, even with changes in illuminant.

For this study, it was assumed that an investigation on the color inconstancy of ink used in everyday analogic processes would be the basis for an assessment on how inconstant digital printing inks used in FineArt printing are. In the spectral energy distribution graph of CMYK inks, it was observed that the curves in the analog processes are quite similar to those in digital. There are some anomalies in the measurements of the flexography datasets, between 380 nm and 400 nm, being below 400 nm, the interference in the visible range is reduced.

As inconstancy is directly related to peaks in the spectral power distribution of the primaries in printing processes, we compared the SPD from Epson7900 inks to offset inks and flexographic solvent inks.

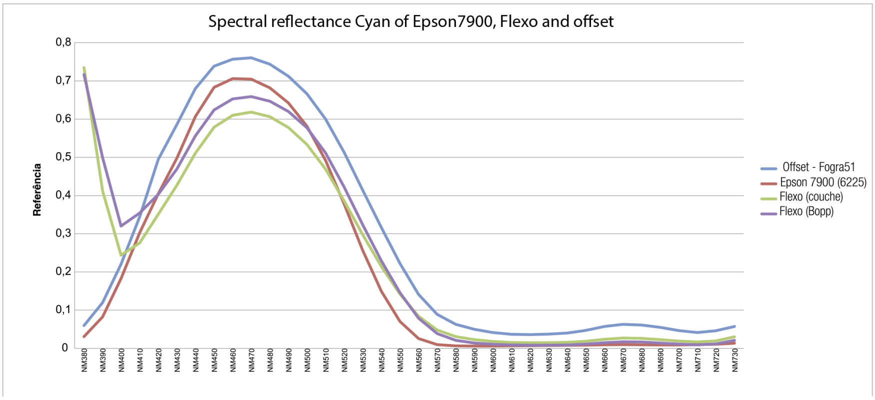

Figure 3a. *Comparing spectral curve energy distribution of Cyan in analogic processes and inks used by Epson 7900.*

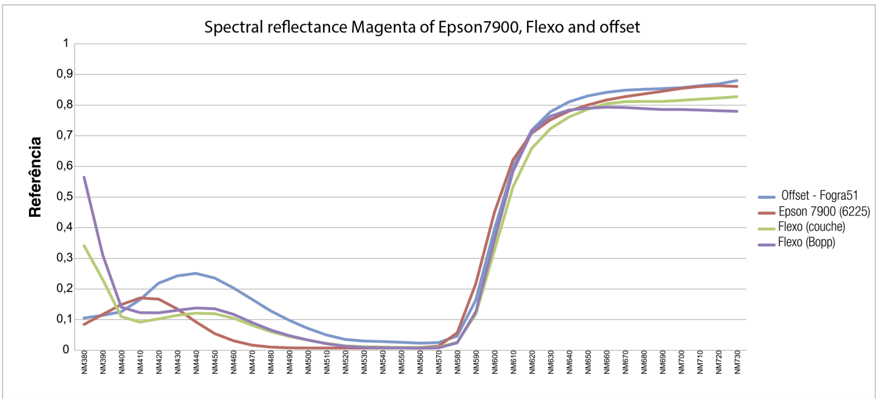

Figure 3b. *Comparison of the spectral curve energy distribution of magenta in analogic processes versus inks used by Epson 7900.*

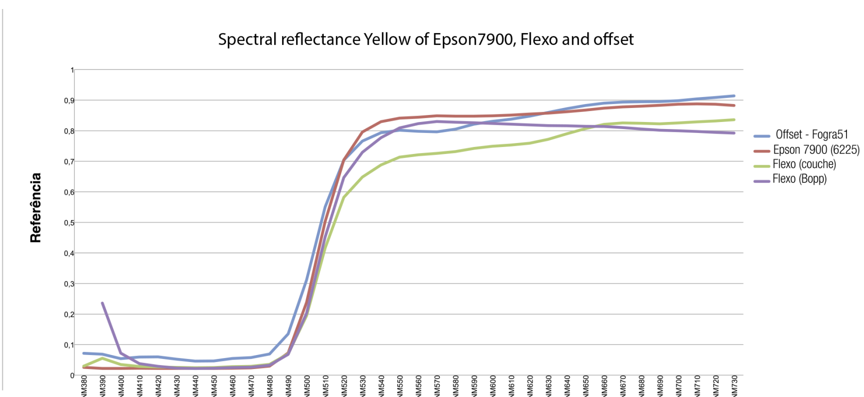

Figure 3c. *Comparison of the spectral curve energy distribution of yellow in analogic processes versus inks used by Epson 7900.*

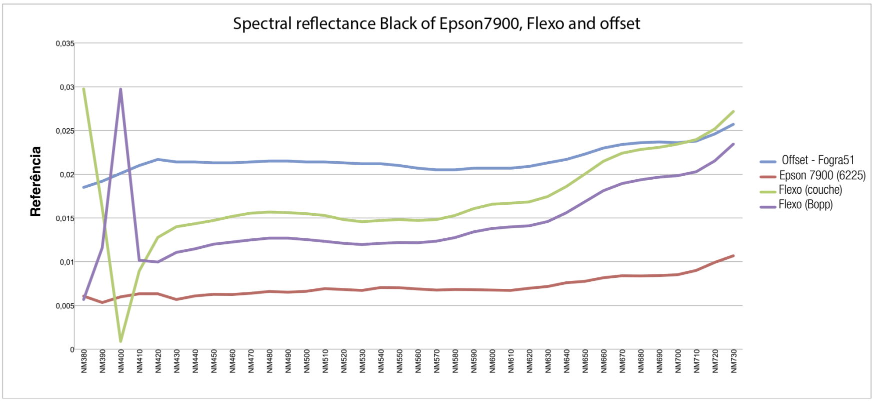

Figure 3d. *Comparison of the spectral curve energy distribution of black in analogic processes versus inks used by Epson 7900.*

This investigation evaluated any differences or anomalies of digital printing inks for Fineart, and since there is no standard with targets and tolerances regarding limits of inconstancy of graphic process inks, the already established graphic processes were used as a guide as to whether there would be any discrepancy of digital printing inks. It is possible to conclude that, despite having a slightly higher inconstancy than offset and flexographic processes, the inconsistency of digital printing inks are not anomalous or problematic.

Printing by RIP (raster image processor) or by printer driver

To address the application of inkjet printing systems for Fineart outputs, it is important to differentiate between device and simulation type printing modes. When using device mode, the transformations are made by the driver at the computer system printing the file. In simulation mode, a RIP is used to simulate a certain printing condition, standardized or not. This is used when you want to make a proof print and the printing system is required to simulate an offset, or flexographic, system by printing CMYK values like those of analog systems for a certain data file. To do this, transformations of the printer's color value data (CMYK or RGB) are required to create an equivalence – which is called a reference print condition.

When starting from a RAW image shot on a digital camera, treated, and acquired in RGB, the colorimetric correspondence of printed areas with the pixels of the original RGB file is expected. Printing in simulation mode results in a rather large gamut limitation. While a printer - like the one used in this study - can achieve a gamut of up to 900,000 DeltaE, simulation mode causes the same machine, using a RIP, to have a gamut below 450,000 DeltaE. This limitation is a key disadvantage for photographic reproduction where a huge gamut is important, and a simulation is out of scope for any photographer or artist.

In the case of Fineart printing, the mode to be used is device mode (driver), that is, a transformation of color values from the original RGB to the printer machine channels via the driver, where each color channel is transformed, regardless of the color value of other channels. Figure5 shows schematically the simulation mode, and Figure4 shows schematically the device mode. For an n-channel device - such as the printer used in this study, which has six channels - single-dimensional transformations are applied to each channel. A channel does not necessarily correspond to a dye; for example, in the printer used, the channels are either CMYKOG, with cyan, cyan light, magenta, magenta light, yellow, orange, green, and three blacks, or only three channels, with RGB data, converted by the driver to the device's inks.

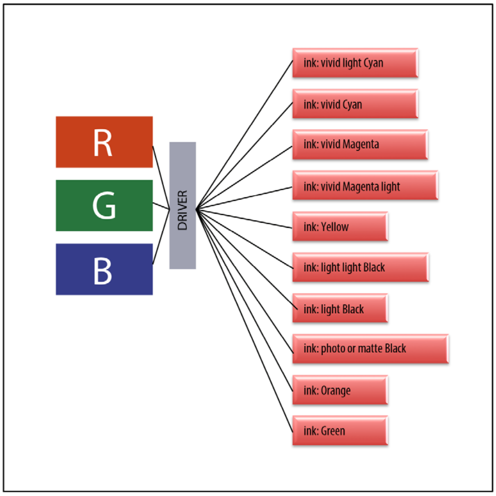

Figure 4. *The CMYKOG color channels accessed by a RIP user and their relationship to the printer inks.*

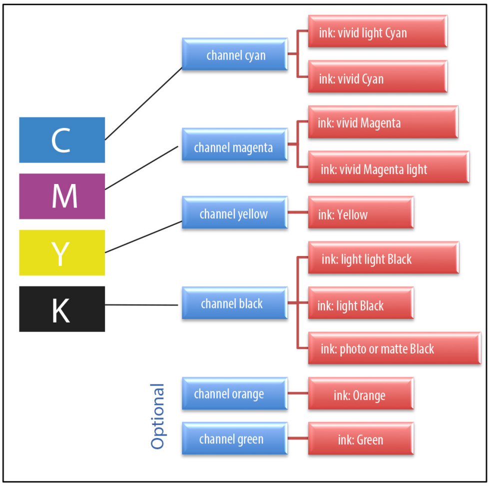

Figure 5. *The CMYKOG color channels accessed by a RIP user and their relationship to the printer inks.*

In general, the user can access only the channels, and the RIP or driver converts the channel data into actual ink quantities for the printer. The RIP is software that determines the ink quantities for each printer dot from a digital file. In this thesis the digital file was made from a photographic image. The RIP can convert input files into ink data addressed to the page to be printed, channel by channel, separating colors by channel and by printer ink. RIPs can interpret vectorized files such as PDFs, image files, and PostScript print files. The RIP involves additional investment in the purchase of a Fineart printer and provides, in general, the following capabilities: (i) control of maximum ink and linearization of each channel; (ii) file assembly on output and output to one or more printers; (iii) color management (transformations of input data to printer/substrate data, with calibration and verification tools; (iv) workflow management (can network with numerous workstations, sending files simultaneously); and (v) cost control.

The driver is a software application that resides on the end user's computer system (to which the printer is connected). Every time the user launches the print menu, in any application (such as Photoshop, Word, etc.), the driver takes over and presents the user with different options. Thus, the user can access the printer's capabilities, such as color management, substrate control, resolution, and speed.

At the beginning of this work, the hypothesis was that the RIP would have more control over color conversions, because it has a much more sophisticated color calibration and verification system than the driver. In the first tests performed with coated paper, the two Fineart printer operation methods proved to be quite equivalent (Table3).

Method	Metrics	D00	D76	ΔH	ΔCh
EFI RIP	Average	1.17	1.99	0.87	1.66
	Max	5.91	7.66	7.58	7.58
	Greys	1.35	1.67	0.47	1.27
	95%	2.50	4.12	2.28	3.72
Epson Driver	Average	1.07	1.88	0.93	1.60
	Max	3.75	6.05	3.62	4.98
	Greys	1.10	1.27	0.43	0.96
	95%	2.31	4.20	2.29	3.57

Table 3. *120-color strip reading results produced by the EFI RIP and Epson driver on EFI paper.*

When comparing the values obtained, the driver presents a small advantage in all items: average of DeltaE00, maximum, 95% percentile and neutrality of the greys (ΔH). With the proximity of the recorded values, the difference between a photograph printed on the two systems would be practically imperceptible, as long as it did not use very saturated colors - in which case there was a greater gain with driver printing, which results in a much larger gamut. As an extra advantage, the calibration of the driver is much faster, while RIP requires additional calibration work, in addition to its acquisition cost, pointing to an advantage in using the driver for museum Fineart prints.

Instrument and measuring mode

In this work, we used the Xrite i1Pro2 spectrophotometer. This instrument can measure in M0, M1 and M2 modes. The nomenclature M0, M1 and M2 is derived from the technical standard ISO 13655:2017. The M0 condition has unknown UV radiation content, or wavelength below 380 nm, similar to an i1Pro1. M1, on the other hand, has a described and known UV radiation content between 330 nm and 380 nm, and the i1Por2 can work in this condition. Thus, M1 was chosen as the most suitable condition, since daylight, sunlight, has contents in this UV range, which, when it hits a substrate or paint with fluorescence, produces light in the visible length range, notably in the blues. Condition M2 is the same as M1 in the visible range, but without UV content, called UV-Cut. Condition M1 was used in this work. Although the normal justification for using M1 mode is to correctly assess substrates that contain optical brighteners (OBA - Optical Brightener Addictive), it is important to note that for long-term preservation or permanence, it is necessary that the substrates do not contain optical brighteners.

Proposed print quality evaluation method

In conventional processes - offset, gravure, and flexography - to control reproductions in printing systems, a control strip, such as the one in Figure6, is added to the printed content.

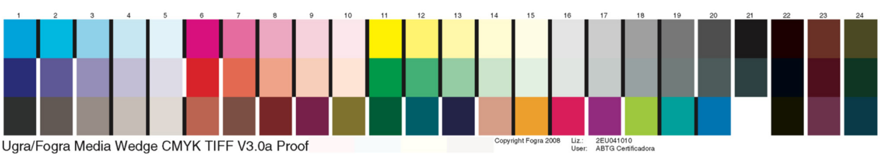

Figure 6. *The Ugra/Fogra Media Wedge V3 control strip. Source: Fogra (2019)*

The basic difference between a direct printing system - such as offset, in which ink values are printed into each CMYK channel directly - and an indirect inkjet system, chosen in our study, is that the conversion from RGB channel values to ink channels takes place inside the driver. This characteristic implies that the color control strategy should not be concerned with channel colors, but rather with deviation tolerances in production, with colors that do not denote process control, but are part of the millions of colors possible to print on a Fineart printing system.

In the control strip above, established in the global printing market, predominate the tints and solids of colors called primary (cyan, magenta, yellow and black), the grays, called greys (composed of quantities of cyan, magenta, and yellow, which result in a neutral grey), of the secondaries (reds, greens and blues) and some tertiaries (brown or maroon).

Currently, there are methods for objective evaluation of printed matter, notably those developed by the ISO Committee on Graphic Technology - TC130. The best known and most used methods are those proposed by the standards ISO 12647-7, which are intended to produce digital proofs before the production of print runs in analog systems (offset, flexography, gravure, etc.). The idea of these prints is to simulate, on a digital press, by means of a RIP color management system, the final print of those conventional systems. In this simulation, the behavior of each primary color of the analogical process, the CMYK, its TVI (dot gain) curves, the values of the secondary colors, the RGB, the balance of grays (increasing amounts of CMY that produce neutral shades of gray) and the size of the gamut (amount of reproducible colors in the process) at the end of the reproduction are observed, whether it is similar or not to the simulated process. All this is to demonstrate that if the printing system is calibrated to the requirements of any part of ISO 12647 (offset, newspaper, gravure, screen printing, flexography), and that the final PDF file will produce a proof that has a very similar appearance to one printed on that analog system.

However, despite the high precision in its specific use in graphic technology, this type of simulation is not suitable for Fineart museum photographic reproductions for three reasons. The first is that the color gamuts of digital processes used in making museum photographic reproductions are different (in format) and much wider than those of analog processes. The second is that the strategy in which a digital inkjet printing system simulates an analog printing process does not apply to Fineart printing, because, in a photographic reproduction, it is important to achieve, as much as possible, the colorimetric values obtained by acquiring the sensor information in RAW. The third is that the ability of the reproduction system to have a gamut equal to or greater than that of the printing system is fundamental in a digital proof universe whistle, in the application that this research is aimed at, it is expected that many values will be achieved, and others will never be achieved, especially those that are extremely bright and saturated and those that are dim and saturated. When comparing the Fineart print gamut and a typical conventional print gamut, the limitation of the proofing system to print Fineart reproductions is noted, as shown in Figure7.

So, the proposed evaluation method will be using a control strip but created with a very different motto than the conventional printing strip as the Ugra/Fogra Media Wedge. The methodology for creating this specific control strip is the next topic.

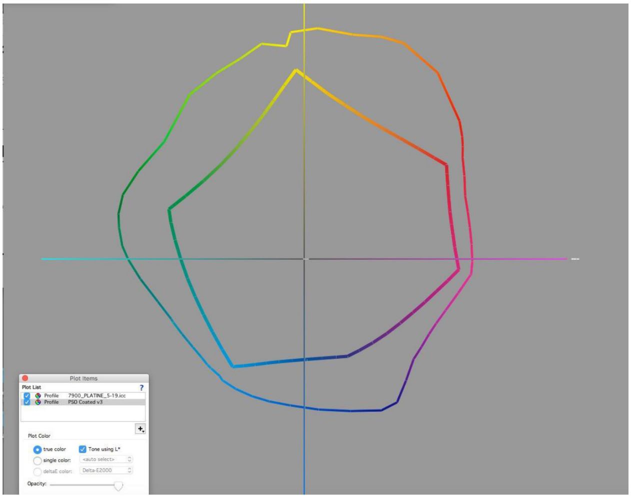

Figure 7. Comparison of gamuts of the wider color space of a Fineart system with Platine paper and an offset process color space.

Creating the evaluation control strip (PRMG CMYK – "agnostic strip")

Initially, when doing the tests for the eventual adoption of the PRMG (CMYK) space, it was verified that, since the PRMG primaries are synthetic, that is, not defined by real dyes, it is impossible to reproduce them with the use of real inks used in Fineart printers, even with substrates with high gamut capacity, as shown in Figure 8.

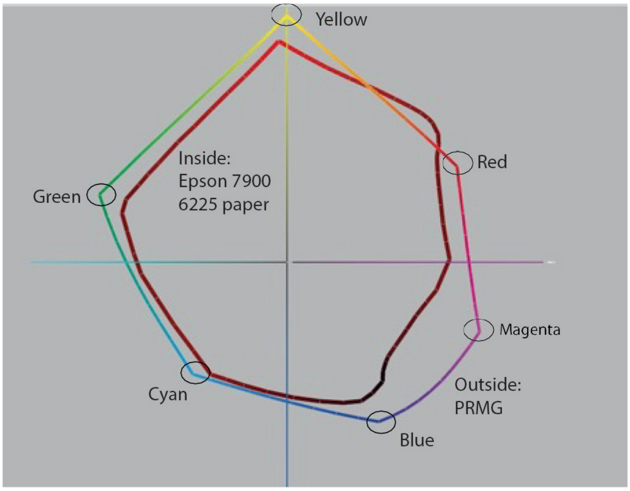

Figure 8. *In the test, the Epson 7900 cannot reproduce any of the primaries or secondaries of the PRMG.*

However, this verification did not present itself as a problem, but as an indication that the value of the PRMG consists in being a fantastic collection of colors reproducible in nature and in photographic processes, besides providing hundreds of colors with special Pantone pigments. To identify the analogic processes in relation to the Epson 7900 and the PRMG, a comparison was made based on the Fogra39 Dataset, which represents an optimum offset printing condition on coated paper and the two cited spaces (Figure9 left). It was identified that the printing system and inks of the Epson 7900 are fully capable of reproducing any offset printed image, i.e., there is nothing that can be done offset with the standard inks that cannot be reproduced on this system. Excess gamut was detected for yellows, oranges, greens, and blues, but not for cyans and magentas. In contrast, comparing the gamuts of the offset process (Fogra39L) and the PRMG printing gamut, it was found that the PRMG has "surplus" in all color areas, especially in the vertices, which are those that determine the size of the gamut (Figure 9 right).

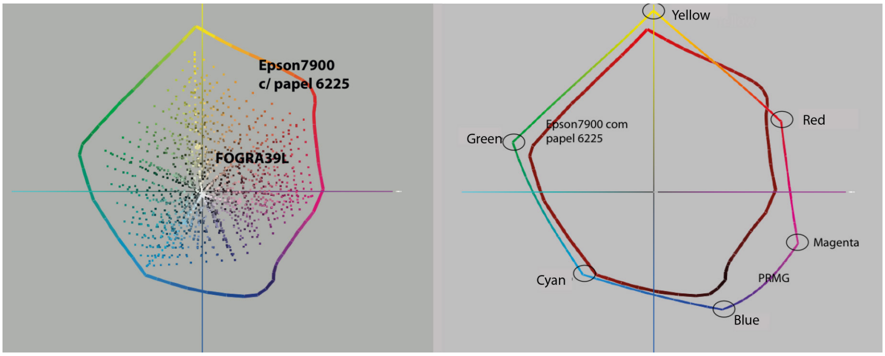

Figure 9. *On the left is the gamut test of offset process, Fogra39L, and "native" Epson 7900 print gamut with good capacity paper; On the right is gamut test of the offset process, Fogra39L, and the PRMG print gamut.*

Based on the capability tests, it was identified that a strip normally used in proofing, in PRMG space, would not be useful, since all PRMG vertices are not printable on the Epson 7900.

Throughout this thesis, it was identified that the image acquisition in ECI-RGB space has advantages over the other color spaces tested and that the RIP printing in CMYK space was outperformed by the driver printing in RGB. From this, it was possible to state that the most suitable flow would be the acquisition, processing, and printing in ECI-RGB space.

The entire color selection and debugging methodology was done colorimetrically, with RGB values in ECI-RGB color space and equivalent values in CIELAB determined.

At the beginning of the work, a control strip was developed with relevant colors in the RGB universe: primaries, greys for color balance, secondaries or subtractives, CMYK and some tertiaries. To choose the colors, a set of images from the Roman16 test control series (BVDM, 2017) were sampled in all chromatic quadrants, as well as achromatic images in various areas of tonal interest (Figure10). Colorchecker colors from Xrite (XRITE, 2019), see Figure11, the standard for the photography world, were also added, based on their CIELAB values.

Figure 10. *Part of the Roman16 images used to sample colors for the initial strip, ECI RGB.*

Figure 11. *The target for calibrating Xrite Colorchecker photo systems*
Source: Color Confidence, 2019.

The control strip was developed with the intention of supplying chromatic elements independent of the printing process. Since it is the driver that decides the ink composition in each situation in Fineart photo printers, the strip does not give greater relevance to the CMYK primaries, as in the case of RIPs, which can control the ink channels individually in the printer. In this case, the chromaticity of the primaries is not hierarchically more important than other colors in the gamut, except for the grays, which are fundamental in determining the quality of photographic images. In this scenario, 126 colors were chosen for the strip, with absolute colorimetric rendering intent.

Figure 12. *Control strip with 126 patches and identification of each color*

Color Universe of the strip: colors from all color quadrants

The colors chosen in the control strip had values within the ECI RGB space - the original space of the Roman16 images -, not representing a real universe of colors in all quadrants. The CIELCH color space was organized according to brightness, chroma and hue, so that colors should be chosen from every quadrant for the new strip.

With this in mind, ISO 12640-3 has been revisited. In one of its annexes is a color chart of all quadrants, every 22.5°, with the luminosity span of the space (Figure13). This chart represents a sample of what can be expressed by the ECI-RGB color space, but it does not mean that there is a printing system capable of reproducing all these colors. Among the origins of the space, as described above, there is a collection of botanical colors (flowers and foliage), Pantone colors, as well as photographic and analogical reproduction processes. It represents an interesting reasoning for extracting colors along the hue circle.

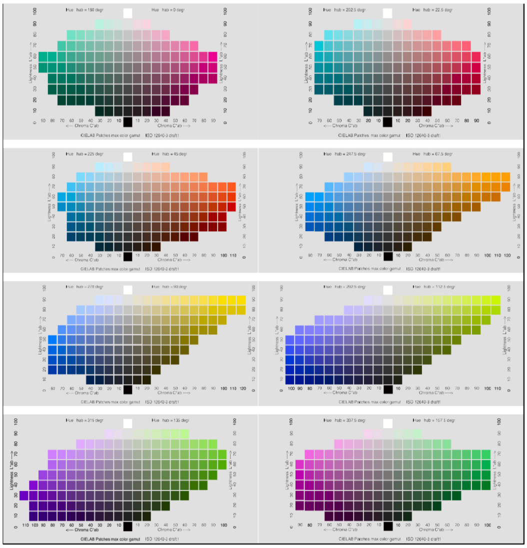

Figure 13. *Descriptive chart of all PRMG quadrants at each 22.5° color angle.*

However, it was observed that in the Fineart printing system, with the Epson 7900 and a fine Fineart paper, the maximum color that can be obtained is lower than the ECI-RGB gamut. To evaluate this limitation, a test was done in Adobe Photoshop: the color cards with a marked ECI-RGB profile were opened and subjected to the Gamut Alert command. The Gamut Alert command paints in gray the colors present in the opened image and impossible to print in the selected output process. In the test, the Epson 7900 printer with EFI 6225 paper was used.

A reasonable range of saturated colors was found, especially in the mid-lights, which the printing system is unable to reproduce. It is important to note that the Gamut Alert evaluation is qualitative, i.e. it does not give an idea of how far each color is from its target in the output system, a tiny DeltaE of impossibility is enough for the mapping to register as an alert.

Despite the observation made about the non-reproducibility of the most saturated colors, a quantitative evaluation of the color collection of the strip printed on the Epson 7900 system shows that there are few limitations in color reproduction (Figure14). In the graph, the statistical distribution of the differences between reference values in ECI-RGB space and the values obtained when printing on the Epson 7900 system can be understood as acceptable, since most of the unprintable patches are in the range between 1 and 3 DeltaE00, a condition considered acceptable in this specific industry.

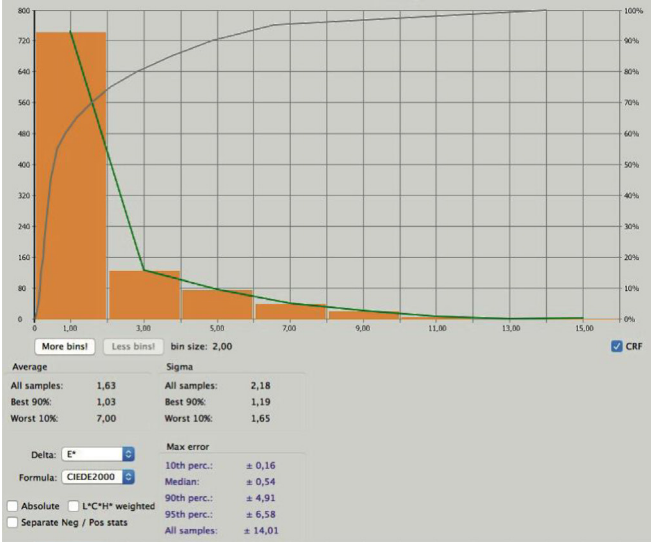

Figure 14. *Statistical Quantitative test of color differences of the Epson 7900 system in the reproduction of the ECI-RGB color space.*

As the strip cannot be too long for reasons of cost and practicality of use, a reduction in the number of colors has been arranged. This procedure started with the elimination of the samples with larger Delta00. These out-of-tolerance values are high, where the read patches are drawn decreasingly by ΔE00. One hundred colors with DeltaE00 above 5 were eliminated: a good starting point for future tolerance setting, since these are difficult colors to reproduce in Fineart printing systems. The inclusion of such colors would force the methodology to raise the tolerance of the maxim to astronomical values.

Next, a distribution was made of the almost one thousand colors according to their tone angle; from this distribution 100 colors were randomly selected; this was the basis for the color control strip. Then all the patches from Xrite's 24-color Colorchecker photo strip were added. To account for a form of process control, gray colors were introduced at strategic points on the CIELAB L* axis. After this procedure, concern arose with another process control measure, always relativized by the scope and application of this work: a reproduction check should evaluate if the external gamut of the color space is represented by the printing system.

From the gamut of the Epson 7900, 100%, 75% and 50% cyan, magenta, yellow and black, respectively, have been inserted, in addition to solid red, green and blue. This means that in the future, when new printing technologies are developed, these colors should be revised. The idea is that the system will work with current technologies. In addition to those listed in the figures above, the colors C100-M100-Y100-K100, C100-M100- Y100-K0 and C0-M0-Y0-K100 have been added in order to give more representation to the darker areas of the reproduction color space. Once this process was finished, as the number of patches was high, very similar colors with small DeltaE between them were eliminated, until reaching a total of 120 patches.

This final strip, plotted with the color spaces obtained on the selected papers (Canson Platine, Canson RagPhotographique, and Canson Etching), seemed to perform well, with only a few patches outside the reproduction spaces - most of them were inside (Figure15). This data corroborated the idea that one was on the right track for the construction of the color strip, with intense work remaining for the creation of tolerances. As in any technical standard, there are limits and tolerances set to achieve compliance, and, in the case of this study, the targets are the colors of the strip, shown in Figures 16 and 17.

Figure 15. *Comparison of the control patches with the color spaces obtained from Platine, RagPhotographique and Etching papers.*

Numerous trials have been conducted to test the validity of the strip regarding reproduction quality and to establish quality criteria between the values originating from the 120 patches of the strip and the values obtained in the Fineart prints. Bellow there are the pictures of the two versions of the control strip, one for rough substrates (wider patches) and other for smooth surface substrates, square patches.

Figure 16. *Final LFP strip, in ECI-RGB, with 120 patches, in all quadrants, with neutrals and with 24 colors from the Xrite Colorchecker. (Note: Wider patches increase accuracy on rough paper.)*

Figure 17. *Final targe for smooth surface papers, with 120 patches, in all quadrants, with neutrals and with 24 colors from the Xrite Colorchecker*

Establishing tolerances of the 120 patches

When determining tolerances, statistical indicators such as quantiles, average and maximum values were used. To check the accuracy of a color patch, numerous printing and measuring trials were carried out using the i1Pro2 spectrophotometer. Then the results obtained from the reading in CIELAB were analyzed against the 120 patches in CIELAB in the reference file with values in the ECI-RGB color space.

The 120 color differences can be expressed in DeltaE1976 (ΔE^*ab), but for this thesis, the more accurate DeltaE2000 ($\Delta E00$) formula was used. According to Martin Habekost (2013, p. 20):

> *Color differencing equations have been in used for quite some time. In 1976 the CIE released the ΔEab-formula, which is still widely used in industry and in research. This formula has its drawback and a number of other color differencing formulas have been issued that try to accommodate how the human observer perceives color differencing in different areas of the color space. Trained and untrained observers in regards to judging color differences were asked to rank color differences of test colors. In both cases the ΔE2000 formula corresponded best with the way both groups of observers perceived these color differences.*

In determining the quality of reproduction, it is possible to interpret the average of $\Delta E00$ values and delimit a maximum $\Delta E00$; however, these two questions alone seemed insufficient to account for the statistical distribution of the 120 values, and a percentile (quantile) of variation was also adopted. After a series of tests, always observing that there are measurement errors that must be treated statistically, it was determined that the requirements of the restrictive ISO standard 12647-7, of a value over a 95% percentile, could be used. As a limit value, a value slightly greater than $\Delta E00=6$ and a maximum value, also greater, of $\Delta E00=8$. These criteria proved effective in the tests with non-rugged papers, such as Canson Platine, that use photo black. In Table4, the requirements adopted are shown and compared with those of the ISO 12647-7 proof standard, considered quite restrictive by the printing industry. In orange are the maximum $\Delta E00$ of the strip patches and the 95th percentile, higher than the proof standard. For the average, the same value was used; and for the greys, very important in photographic reproduction, a more restrictive value was used: 1.5 ΔH.

Rules for smooth papers		ISO 12647-7
Average ΔE00	2.50	2.50
Max ΔE00	8.00	5.00
Average ΔH	2.00	-
95% ΔE00	6.00	5.00
95% ΔH	5.00	-
Greys ΔH	1.50	2.00

Table 4. *Requirements for color striping, on non-rugged (usually coated) substrates (left), according to this work, compared to ISO 12647-7, proofing standard (right).*

However, for prints on rough substrates, such as Canson RagPhotographique and Canson Etching, because of the errors determined by the mandatory use of matte black and the most frequent reading errors - arising from the difficulty of reading on the irregular paper surface - a lower percentile of 80%, with the same ΔE00 limit of 5, was chosen for use. However, the maximum value had to be set to ΔE00 15; this value would, from the point of view of the printing industry, for example, be unacceptable. However, with statistical treatment of 80% percentile below ΔE00 of 5, very interesting results were obtained (Table5).

Rules for smooth papers		ISO 12647-7
Average ΔE00	3.50	2.50
Max ΔE00	15.00	5.00
Average ΔH	2.00	-
95% ΔE00	5.00	5.00
95% ΔH	2.00	-
Greys ΔH	1.50	2.00

Table 5. *Requirements for color striping, on rough substrates (left), according to this work, compared to ISO 12647-7, proofing standard (right).*

Table5 shows the requirements adopted for rough substrates and compared with those of the ISO 12647-7 test standard. The values of maximum ΔE00 for 15, average for 3.5, and 80th percentile for 5 ΔE00 were adjusted. For the greys, very important in photographic reproduction, a more restrictive value of 1.5 ΔH was employed.

Conclusions

The hypothesis initially proposed by this work were as follows:

- Is it possible to develop an objective methodology for evaluating the quality of Fineart reproductions of images generated by capture in professional digital cameras?

- If the methodology is robust enough, does it have the potential to be widely adopted among stakeholders interested in the quality and permanence of photographic artwork from digital cameras, to contribute to the reliability of printmaking and to the development of this segment of the arts?

The empirical results obtained in this thesis pointed to quite precise and effective questions for the Fineart museum photographic originals evaluation methodology, namely:

- the definition of the ECI -RGB image acquisition and processing space;
- the definition of the shape and colors of the control strip - systematic choice of colors and reasonable number of samples;
- the definition of the print color space (RGB) and, as a consequence, the control strip in this space;
- the definition of the numerical queries for the interpretation of the targe reading;
- requirements for papers with pronounced roughness;
- requirements for plain paper; and
- creation of a scoring system to facilitate the adoption of the methodology.

The methodology was tested in numerous trials and proved to be robust enough to be proposed as a requirement for evaluating Fineart reproduction of digital photographs. In this sense, it aimed to simplify the procedures, without compromising their accuracy.

It is important to note that most printing systems that meet the requirements defined as a Fineart printing system - that is, being inkjet, water-based, pigmented inks, number of channels above 8, and use of museum substrates - can meet the printing requirements of the physical strip without too many difficulties.

The final products for the use and practical implementation of this work are described as follow:

- Control strip to be printed next to the photograph in the Fineart printing system;

- Methodology of instrumentation (measurement) with spectrophotometer, of the color control strip and archiving of the values for later calculation in a spreadsheet;

- Worksheet with a tab for rough substrates (requiring black matte) and another for less rough or coated substrates (which use photo black).

The criteria tested during the work support parameters that make the use of the methodology practical and correlate to the quality that can be obtained with Fineart printing systems on museum substrates.

The use of this methodology allows establishing, in a clear and objective manner, the quality of Fineart reproductions. It is expected that its adoption will help artists/photographers, gallery owners, museums, and collectors to objectively qualify Fineart reproductions. The major benefit would be to separate conforming reproductions from nonconforming ones in a pragmatic way, eliminating, where possible, subjective visual evaluations. With this, all risks of abstract evaluations are extinguished, especially of the observer's skills (visual ability to discern colors) and of the illuminant - not always the one proposed by ISO 3664. Regarding the illuminant present in the evaluation spaces, it is observed that the Fineart printing system used does not present color inconstancy notably superior to traditional printing systems (offset and flexographic). This finding indicates that all the care with the exhibition spaces that should be observed with these materials is sufficient for Fineart reproductions.

As for its use, the methodology is quite simple, requiring a spectrophotometer and a spreadsheet. The results can also serve as a basis for providers to know if they have reached a point of recalibration of their printing systems, and for specialized consumers, such as artists/photographers, gallery owners, and museums, to evaluate prints received for collections, shows, and exhibitions.

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