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PARAMETRIC COLOUR ANALYSIS OF IMAGES FROM CRETAN SCHOOL OF HAGIOGRAPHY (15th – 17th c.AD) USING THE CIELab MODEL

Vlisidi A.[1], Doulamis A.[2], Bakolas A.[1], Moropoulou A.[1]

[1]National Technical University of Athens, Department of Materials Science and Engineering School of Chemical Engineering, Iroon Polytechniou 9, Zografou Campus 15780 Athens, Greece
[2]National Technical University of Athens, Department of Topography School of Rural, Surveying and Geoinformatics Engineering, Iroon Polytechniou 9, Zografou Campus 15780 Athens, Greece

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Corresponding author: Antigoni Vlisidi, antigonivlisidi@gmail.com

ABSTRACT

The Cretan School was an important school of hagiography that flourished during the 15th, 16th and 17th centuries, while Crete was still under Venetian rule and reached its peak after the Fall of Constantinople, being the central expression of Greek painting. Cretan artists developed a particular style of painting under the influence of both Eastern and Western artistic traditions and movements. By the end of the 15th century, Cretan artists had established a distinctive style of hagiography, distinguished by the dark brown flesh formation and the dense microscopic highlights on the cheeks of the faces, the bright colours in the garments and, finally, the colour balance of the overall composition. This paper focuses on investigating the nuances of the images of this School in order to determine whether the artists of this period follow a common colour pattern. For this purpose, the CIELAB colour analysis method was used, during which the three colour parameters (L*, a* and b*) were measured in 48 digital images of representative hagiographies of the Cretan School of period 1 and from these the combined colour parameters (h*, C* and E*) were calculated through mathematical processing. The statistical analysis of all the interrelationships of the parameters revealed two strong linear correlations between a) the brightness of the images (L*) and their total colour coefficient (E*) as well as b) the yellow tint coefficient (Δb*) of the images with the colour saturation coefficient ΔC*. The corresponding linear relationships were found a) (ΔE*)=1.218 (ΔL*)- 9.69, with R^2=0.91 and b) (Δb*) = 1,043 (ΔC*)+0.36 with R^2=0.97) which proves that yellow/blue hue prevails in all images and that the brightness of the image depends on the geometric mean of the set of all colours. Due to the high correlation of Δb* with ΔC* (R^2=0.97) this information could be used as a preliminary estimate of whether an unknown hagiography could belong to the Cretan School.

KEYWORDS: art, CIELAB colorimetric method, Cretan hagiography School, non-destructive method, Byzantine art

1. INTRODUCTION

Byzantine hagiography is the art of depicting saints and religious subjects, in order to bridge the natural with the spiritual world. After the Seventh Ecumenical Council, which took place in Nice in 787 AD, the subjects of hagiography are presented with a defined iconographic historical circle in the church, which will become the norm in Byzantine hagiography. In this cycle, there are twelve themes, taken from usual scenes from the Nativity to the Ascension of Christ, as well as icons of Saints where certain strict rules have been established for their depiction, such as, it is necessary for painters to faithfully depict the characteristics of holy persons, as they have been handed down either from older written texts or from various visual media. Thus, there is a repetition over the centuries of a strictly defined fixed pattern of shapes and forms, such as saints must be portrayed as strict but also indulgent, exude spirituality, and not be smiling and have a worldly expression. Also, the presentation of the image must eliminate the space and the time as well as the perspective of shapes. The development of the art of hagiography from the Seventh Ecumenical Council to the Palaiologan era was catalytically influenced by the Hellenistic and Eastern art of painting, creating the art of Byzantine hagiography (Tsigaridas, 2016; Daniilia, 2007). The full maturity of Byzantine hagiography comes during the era of the Palaiologos which is considered the golden age of hagiography. Hagiography also takes on Western influences and becomes more "narrative" seeking to touch emotion. The French archaeologist G. Millet (Jolive-Levy, 2013) divides the Byzantine iconography of the Palaiologan era (Anagnostopoulos, 2023) into two schools: the "Macedonian" and the "Cretan". These are two different trends, two different ways of approaching Byzantine hagiography.

1.1 The Cretan School

The Cretan School of Iconography was developed mainly at the end of the 14th century, during the Renaissance, by artists expelled from Constantinople who moved to Mystra, Mount Athos, Meteora and mainly to Crete (Hatzidakis 1974). Its main features are the darker models, mainly on the faces, where the brown and not the green colour of the Macedonian School is used. This School remained more faithful to the style of Byzantine hagiography whose main characteristics are restrained movements, austerity and nobility of persons and generally to the adherence of Byzantine traditions with mystical and ascetic character. Light is now scarce and seems to come from some depth, an element that submits deep devotion to the viewer. The Cretan style was considered as the art of the monks as many of the post-Byzantine painters embraced the monastic life and created within the confines of the monasteries (Mastrotheodoros et al 2022). Art at that time was not a simple religious approach, but a performance full of symbolism. Byzantine Art has strict rules and codes, which where common not only for the artists to apply but also for the public to perceive a work of art (Bozas, 2021). Thus, we see a repetition over the centuries of a strictly defined formula for each sacred person. In the depiction of religious subjects, certain rules have been established (Byzantine Orthodox hagiography, 2019).

1.2 The hypothesis and the aim of this Study

Within these strict frameworks, artists had limited possibilities to develop any personal style of painting so that it could be easily identified. However, a significant painting degree of freedom each painter had was in the use of colours in his work. This freedom led each artist, consciously or unconsciously, to a certain pattern of qualitative and quantitative use of colours and shades in all his works. Based on this hypothesis and by analysing with appropriate mathematical techniques the colour pattern of a painter's works, the particular artistic style of the artist could be revealed (Kaminari et al., 2021). In the same way, chromatic analysing the works of all the artists of a time period could perhaps reveal the particular color trend of the works of that period (Liang 2012, Alfeld et al., 2017; Cartechini et al., 2021).

1.3 Colorimetry and CIELAB model

Colorimetry is the science that deals with the physical description of human perception of color (CIE, 1995). As a science, it appeared in 1930 by the CIE (International Commission on Illumination). Through colorimetry it becomes possible to quantify and physically describe color as it is perceived by the human eye. The technique that characterizes colorimetry is the determination of three-color values, red, green and blue, which placed in a three-dimensional color space can simulate the perception of the human eye (CIE, 1995) for any coloured light. CIE developed various color systems that do not depend on imaging devices but are based on mathematical representations of colours. In 1976, CIE presented the CIELAB model, which is now proven to simulate in the best way of all other systems, the human perception of color differences. Each color is described by three color parameters, L^*, a^* and b^*, represented in a three-dimensional Cartesian coordinate system. The L^* parameter contains the luminance information and takes values from 0 (black) to 100 (white) while the parameters a* and b* have no value limits and contain the color information. The a* coordinate represents the green/red element of the color while the b* coordinate represents blue/yellow. In addition to three-dimensional Cartesian coordinates, the CIELAB color model can also be represented in a cylindrical polar coordinate system in the form of CIE L, C*, where C* represents the chroma that determines the relationship between color intensity and brightness of the studied hue while h^o (hue angle) represents its hue (McGuire, 1992; HunterLab, 2008, 2018). Also, the parameter E* expresses an overall geometric mean value of all three-color parameters L*, a* and b*. The color parameters C*, E* and ho are derived from mathematical relationships as presented in Table 1.

Today the CIELAB model is effectively used in various industrial applications such as food quality control (Abbott, 1999; Perkins-Veazie, et al.) or is used for quality control of various biological processes such as of quality control of the final product of an agricultural composting process (Tsivas et al., 2021; Palechor-Trochez et al., 2018; Ashik Iqbal Khan et. al., 2009). Today, the possibility of lightweight and easy-to-use portable instruments that allow in-situ non-destructive measurements make colourimetry very attractive for the examination and analysis of cultural heritage objects and monuments. In addition, the results are obtained easily and quickly allowing statistical processing and straightforward comparisons with previous results obtained from the same or similar monuments (Biscontin et. al., 1994).

The CIELAB colour system is considered the best adapted to the subjective perception of colour by the human eye and consists of three axes: L* axis or light/dark axis, a* axis or red/green axis and b* or blue axis /yellow axis (Dyer at el., 2013; CIE, 1995). The direct measurement, by means of a specific colorimeter, of the basic colour variables L*, a* and b* as well as the calculated variables ΔL*, Δa*, Δb*, Δho*, ΔC* and ΔE* resulting from the basic variables (Table 1) is a tool for the mathematical expression of the colour characteristics of an image (Ricca et. al., 2023; Leon et al., 2006). Cross-correlation of colour variables collected from several paintings by the same artist could reveal the particular and unique artistic character of the painter. The CIELAB method as a non-invasive technique is an attractive method because of the quick in situ application, the absence of expensive consumables, the inspection of the entire surface of the object and the mapping ability, offering the advantage of examining large areas of an image (Luo et. al., 2001; Sharma et al., 2005). The CIELAB colour method has already been successfully used to quantify the temporal deterioration of monuments and statues (Ficher et. al., 2006; Brunetti et. al., 2016; Maev et al., 2008). Spectral and multispectral image analysis was also used as a simple, low-cost method for designing art conservation paints (McCuire et al., 1992: Orfanides 2016; Daniel et al., 2016).

Non-destructive testing with an emphasis on spectral imaging, especially in the optical domain, is the forefront of diagnostic methods, constituting a low-cost valuable tool (Kleynhans et al., 2021) at the service of art historians, scholars, conservators and researchers (Vlisidi et al., 2016, 2024; Leon et al., 2006). In this study, our research focuses on the period after the fall of Constantinople, where Cretan art began to develop with influences mainly from the Palaiologan School and the early Italian Renaissance. The aim of this work was the colour analysis of a sufficient number of representative frescoes of distinguished Cretan School painters of the 14th,15th and 16th centuries such as Theophanes, Georges, Damaskinos, Pavias, Ritzos, Klontzas, Lambardos, Bounialis, Poulakis and others by using the CIELAB method. All colour variables were calculated to find specific characteristic colour expressions for each artist as well as a common possible characteristic colour design basis for the Cretan School of hagiography.

2. RESEARCH METHODOLOGY

2.1 Image collection and proper modifications

Forty-eight digital images of hagiographies of the 14th-17th c. DA period were collected from various sites on the Internet (see Table 2). All the images were shrunk uniformly over the whole image so that the percentage of colorations is not altered even after the image has been shrunk. This reduction is achieved with a suitable software available from the CorelDRAW design program. This shrinking is necessary so that the entire image covers the visual field of the spectrophotometer.

2.2 Color measurement

Color measurements were conducted with a Dr Lange spectrophotometer (Hach Lange LMG 183), a portable colorimetric device that uses standard circular viewing geometry d/8o, an illuminant D65/100 and two calibration standards (LZM 268), one black (X=4.07, Y=4.35, Z=4.59) and one white (X = 83.78, Y = 88.60, Z = 90.39). Before each colour measurement the colorimeter was calibrated using the above calibration standards. Colorimeter sensors with the help of special filters simulate the function of the human eye and colour measurement is achieved with the use of an artificial light source (Alfeld et al 2017; Cartechini et al 2021).

For measuring the three-color variables, L*, a* and b* (CIE 1995), any image of any magnitude must be uniformly classified in an area of 2.5*2.5 cm, as that was the field of view of the LMG 183 spectrophotometer. Using this type of scaling, the qualitative and quantitative ratio of the colours does not change, and therefore, the values of the colour variables do not change either. At the same time, these measurement values correspond to the whole image, which is what we are looking for. Thus, for any image the three chromatic parameters: L*, a*, and b* were retrieved. The value of parameter L* refers to color luminance ranging from 0 (black) to 100 (white), a* represents the green/red component ranging from negative (green) to positive (red) values, and b* represents the blue/ yellow component ranging from negative (blue) to positive (yellow) values (Dyer et al., 2013; Kleynhans et al., 2021), Additionally, hue angle h° (Palechor-Trochez et al.,2018), Chroma C* (Perkins-Veazie, 2001) and total colour difference ΔE* (Sharma et al., 2005), derived from the CIELAB colour model were calculated according to the mathematical relationships presented in Table 1. The selected and then adapted images are presented in Fig.1.

Table 1. The CIELAB variables used in this study

Variables	Equation/description	Reference
L*	Lightness ranging from 0 (black) to 100 (white). Difference $\Delta L^* = L^*_{sample} - L^*_{standard}$	(CIE, 1995)
a*	Green/red component ranging from negative (green) to positive (red) values. Difference $\Delta a^* = a^*_{sample} - a^*_{standard}$	[CIE, 1995)]
b*	Blue/yellow component ranging from negative (blue) to positive (yellow) values Difference $\Delta b^* = b^*_{sample} - b^*_{standard}$	[(CIE, 1995)
Hue (h°)	$h^{o*} = \tan^{-1}(b^*/a^*)$ Difference $\Delta h^{o*} = \tan^{-1}(\Delta b^*/\Delta a^*)$	(Leon, 2006
Chroma (C*)	$C^* = (a^{*2} + b^{*2})^{0,5}$ Difference $\Delta C^* = (\Delta a^{*2} + \Delta b^{*2})^{0,5}$	(Luo, 2001)
Chromatic quotient	$\Delta a^*/\Delta b^*$	(Luo, 2001)
Total color E*	$E^* = (L^{*2} + a^{*2} + b^{*2})^{0,5}$ Difference $\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{0,5}$	(Sharma, 2005)
Δ(variable)	Differences between the measured correspondence variable from spectrophotometer and correspondence substrate of every image. This difference eliminates the possible effects of the image substrate and homogenizes the results.	

1.Theotokopoulos 2 Theofanis 3 Unknown artist 4 Tzanes 5 Theofanis 6 Theofanis
7 Pavias 8 Theofanis 9 Damaskinos 10 Damaskinos 11 Damaskinos 12 Damaskinos
13 Damaskinos 14 Theotokopoulos 15 Unknown artist 16 Unknown artist 17 Damaskinos 18 Damaskinos

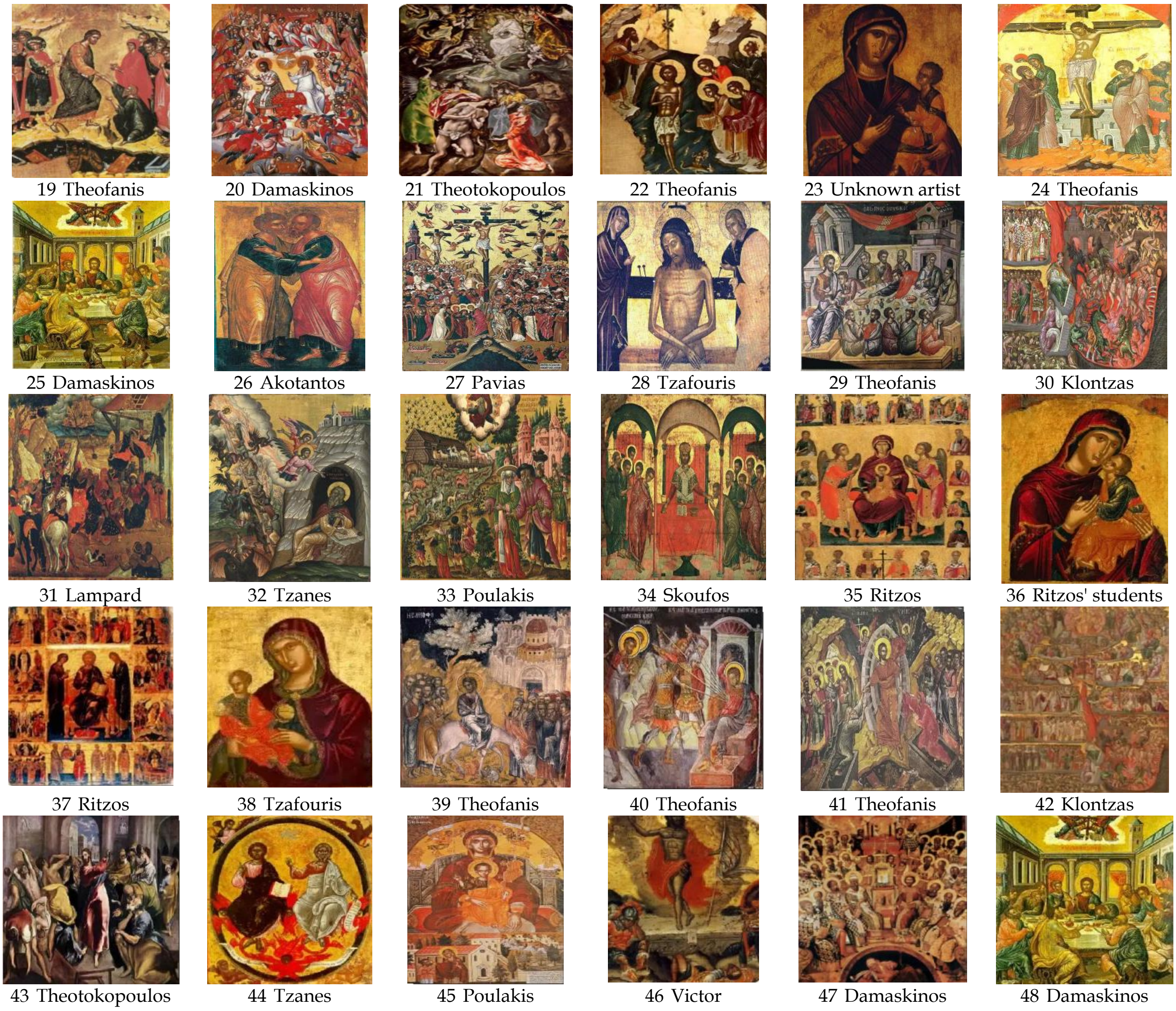

Figure 1. Hagiographies of Cretan School that were examined in this study using CIEBLAB method. Numbers are credited sources at the end of references.

2.3 *Regression Analysis*

The statistical regression analysis was applied to estimate the relationships between the CIELAB colour variables as well as of their standard deviation. Linear types of equations were tested to determine the strongest relationship between the variables expressed with Pearson's correlation coefficient, R^2 (i.e., the highest value) (Cohen et al., 2007; Snedecor et al., 1989) and simultaneously with the smallest standard deviation. The existence of a linear relationship of CIELAB variables with a fairly high R^2 coefficient value and a corresponding low standard deviation value will be strong evidence that each artist has a certain colour identity. The proof of this individual colour character of each of the two painters is the main goal of the research presented in this paper.

3. RESULTS AND DISCUSSION

The measurements of ΔL*, Δa* and Δb* as well as the calculated CIELAB variables (Δh*, ΔC* and ΔE*) from the frescoes of Figure 1 are presented in Table 2. Moreover, in Figure 2 the linear relationships between these variables are presented. Also, in Table 3, the correlation coefficients (R^2) of these relationships are presented.

Table 2. Results of measurement and calculations of the CIELAB variables for the paintings of Fig. 1

	Measurements			Calculations				Measurements			Calculations		
No	ΔL*	Δa*	Δb*	Δh*	ΔC*	ΔE*	No	ΔL*	Δa*	Δb*	Δh*	ΔC*	ΔE*
1	63,00	8,55	15,86	-0,29	18,02	65,53	25	58,14	2,61	25,83	1,96	25,96	63,67
2	55,23	-0,93	11,80	-8,17	11,84	56,48	26	51,15	4,01	9,73	-1,2	10,52	52,22
3	61,74	18,51	21,58	0,43	28,43	67,97	27	62,44	1,01	15,14	-1,2	15,17	64,26
4	50,48	4,39	9,58	-0,70	10,54	51,57	28	62,79	3,99	11,05	-2,5	11,75	63,88
5	53,12	3,80	9,92	-1,70	10,62	54,17	29	54,54	1,11	8,30	0,40	8,37	55,18
6	59,20	6,55	12,31	-0,32	13,94	60,82	30	52,75	7,12	10,08	0,16	12,34	54,17
7	58,86	4,60	17,06	1,57	17,67	61,45	31	54,85	6,81	13,72	-0,5	15,32	56,95
8	53,98	4,33	9,11	-0,59	10,09	54,91	32	58,61	5,02	12,31	-1,2	13,29	60,10
9	60,70	12,56	22,71	-0,24	25,95	66,02	33	54,48	2,35	13,30	-1,4	13,51	56,13
10	56,16	6,30	17,42	-2,53	18,52	59,14	34	60,88	10,90	23,33	-0,6	25,75	66,10
11	53,49	1,34	12,70	18,91	12,77	54,99	35	54,61	9,88	17,69	-0,2	20,26	58,25
12	55,15	5,29	14,97	-3,10	15,88	57,39	36	54,71	9,75	20,38	-0,6	22,59	59,19
13	56,61	6,03	9,14	0,06	10,95	57,66	37	57,58	11,98	21,91	-0,3	24,97	62,76
14	56,90	3,11	10,02	12,43	10,49	57,86	38	57,38	9,69	22,91	-1,0	24,87	62,54
15	56,68	1,21	6,00	-0,25	6,12	57,01	39	62,56	8,04	16,23	-0,5	18,11	65,13
16	63,22	-1,20	6,24	0,53	6,35	63,54	40	58,54	7,99	12,17	0,05	14,56	60,32
17	66,13	11,18	36,71	7,00	38,37	76,46	41	60,15	3,70	10,23	-2,5	10,88	61,13
18	52,73	6,47	15,44	-1,06	16,74	55,32	42	55,49	7,58	15,62	-0,5	17,36	58,14
19	56,15	6,64	14,29	-0,66	15,76	58,32	43	51,23	5,02	5,26	0,6	7,27	51,74
20	63,75	8,40	15,17	-0,24	17,34	66,07	44	61,20	10,16	27,17	-2,0	29,01	67,73
21	53,51	2,56	7,66	-6,64	8,08	54,12	45	60,53	15,57	22,62	0,12	27,46	66,47
22	56,64	6,97	19,69	-3,05	20,89	60,37	46	50,74	12,99	12,12	0,74	17,77	53,76
23	47,89	8,50	12,92	0,05	15,47	50,33	47	57,37	8,42	18,02	-0,7	19,89	60,72
24	76,03	-1,18	32,71	1,62	32,73	82,78	48	58,96	3,29	26,69	-0,3	26,89	64,80
							Mean value =	**57,48**	**6,30**	**15,82**	**0,02**	**17,36**	**60,35**
							Standard deviation =	**23,23**	**17,64**	**47,38**	**15,42**	**53,44**	**38,00**

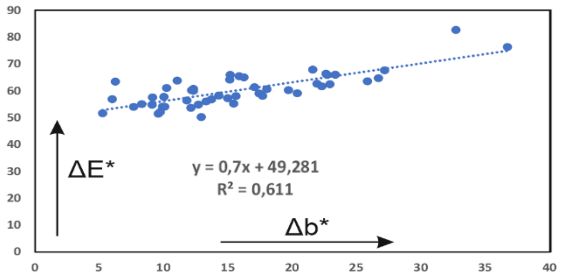

Figure 2.1: Linear relation between Δb* and ΔE*

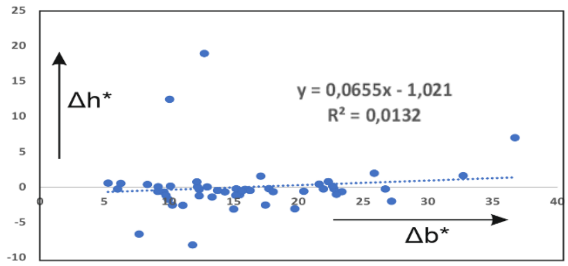

Figure 2.2: Linear relation between Δb* and Δh*

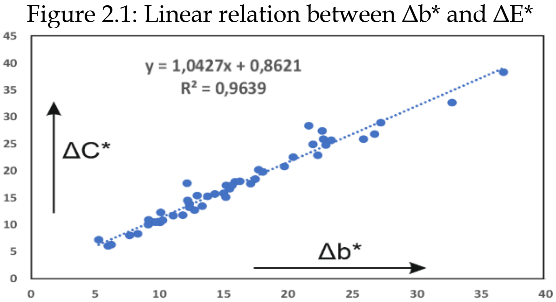

Figure 2.3: Linear relation between Δb* and ΔC*

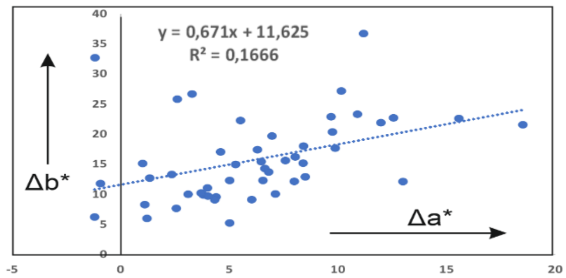

Figure 2.4: Linear relation between Δb* and Δa*

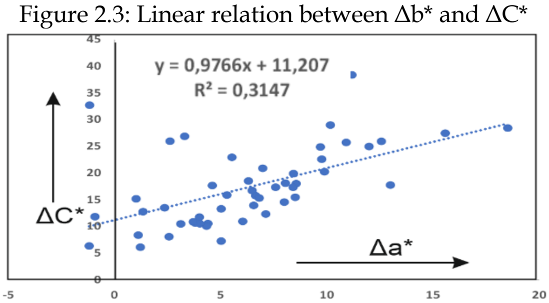

Figure 2.5: Linear relation between Δa* and ΔC*

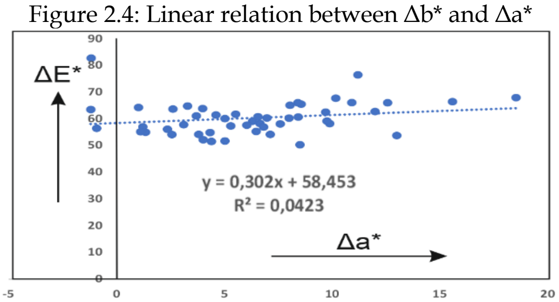

Figure 2.6: Linear relation between Δa* and ΔE*

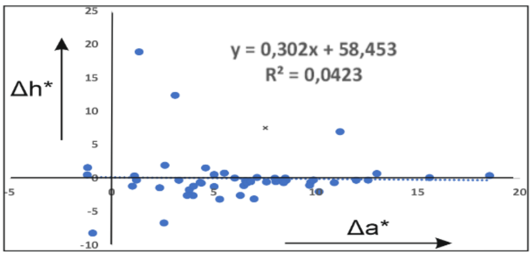

Figure 2.7: Linear relation between Δa* and Δh*

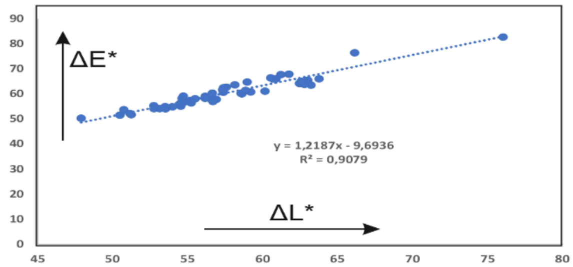

Figure 2.8: Linear relation between ΔL* and ΔE*

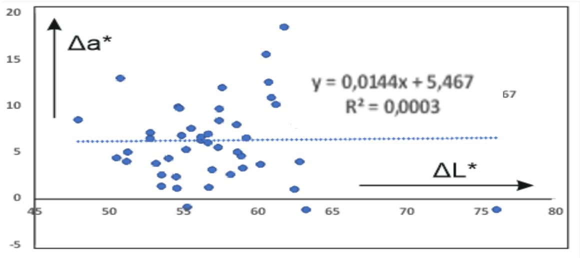

Figure 2.9: Linear relation between Δa* and ΔL*

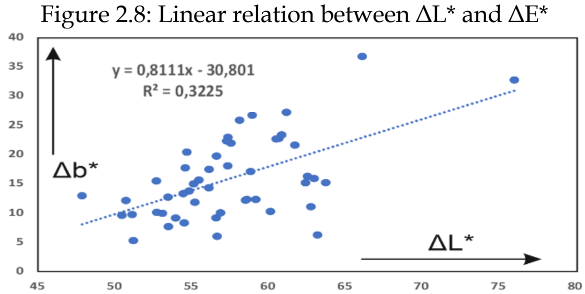

Figure 2.10: Linear relation between Δb* and ΔL*

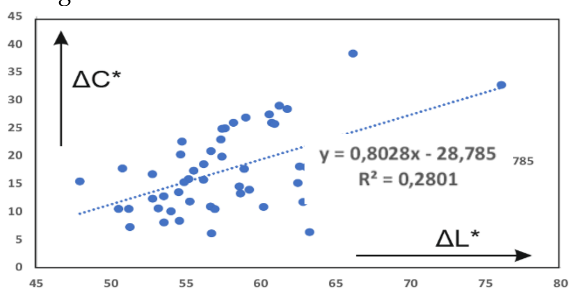

Figure 2.11: Linear relation between ΔC* and ΔL*

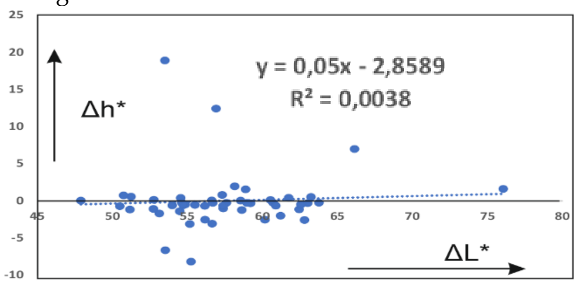

Figure 2.12: Linear relation between ΔL* and Δh*

Figure 2. Linear cross correlation between color parameters of hagiographies of Fig. 1

Table 3. Correlation coefficients R^2 of the linear relationships between CIELAB variables

	ΔL*	Δa*	Δb*	Δh*	ΔC*	ΔE*
ΔL*	-	0,0423	0,3225	0,0038	0,2801	**0,9079**
Δa*	0,0423	-	0,1667	0,0423	0,3147	0,0423
Δb*	0,3225	0,1667	-	0,0132	**0,9639**	0,611
Δh*	0,0038	0,0423	0,0132	-	0,0354	0,0122
ΔC*	0,2801	0,3147	**0,9639**	0,0354	-	0,658
ΔE*	**0,9079**	0,0423	0,611	0,0122	0,658	-

According to the results of Table 3, the best statistical fittings of these relationships were found in Figure 2.3 (Δb* → DC* with $R^2 \approx 0.97$, with a slope of straight line 1,042) and in Figure 2.8 (ΔE* → ΔL* with $R^2 \approx 0.91$, and with a slope of straight line 1.22). These results indicate that the brightness of the images (ΔL*) depends on their total colouring of them and also, they are characterized mainly by shades of yellow and much less of the other shades.

4. CONCLUSION

The analysis of icons from their digital images using the CIELAB method is a new non-destructive method of roughly preliminary study of hagiographies through color analysis of the image as a whole. This method reveals through contemplative mathematical relationships the distinct color preferences and tendencies of an artist and possibly a group of artists belonging to the same School. The present research attempted to investigate this hypothesis using the CIELAB method to analyze the color preferences of many painters of the Cretan School. It was found that all the works of various hagiographers of the Cretan School converge in a linear relationship of the color parameters a) Δb* and ΔC*: (ΔC*) = 1.0427; (Δb*) + 0.8621 with R2 = 0,97 and

b) (ΔE^*) =1.218 (ΔL^*)- 9.69, with R^2=0.91. According to the equations of table 1 and the above relationships, the Lightness of digital images of hagiographies from the Cretan school, depends on the geometric mean of the set of all model CIELAB basic chromatic parameters of the images. Due to the high correlation of Δb^* with ΔC^* (R^2=0.97) this information could be used as a preliminary indicative assessment of whether an unknown hagiography could belong to the Cretan School.

Authors Contribution: A.V (PhD NTUA student): performed all the history of art analysis, the laboratory work for the cielab analysis; A.M: chief scientific supervisor, design of the research, assesment and evaluation of results; A.B: specific colorimetric analysis; A.D: statistical correlation of the parameters.

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