Check for updates

Received: 30 May 2022 | Revised: 13 March 2023 | Accepted: 24 March 2023

DOI: 10.1002/col.22856

COLOR RESEARCH AND APPLICATION WILEY

RESEARCH ARTICLE

Color induction in the restoration of architecture in historic city centers

Juan Serra | **Ignacio Cabodevilla-Artieda** | **Ana Torres-Barchino** | **Jorge Llopis**

Color Research Group in Architecture (GICA), Heritage Restoration Institute (IRP) School of Architecture (ETSA), Universitat Politècnica de València (UPV), Camino de Vera s/n, 46022 Valencia, Spain

Correspondence
Juan Serra, Color Research Group in Architecture (GICA), Heritage Restoration Institute (IRP) School of Architecture (ETSA), Universitat Politècnica de València (UPV), Camino de Vera s/n, Valencia 46022, Spain.
Email: juanserra@ega.upv.es

Abstract

In the restoration of historic facades, specialists need to tackle the problem of colors applied to the ornamental elements that appear different on a facade than if they were isolated, because the colors of the surrounding surfaces influence them through color induction. This study evaluates the difference between the colors of ornaments observed in isolation, which we call nominal colors, and on different background colors, which we call induced colors, considering the historic color palette of Valencia as studied by the Color Research Group in Architecture of the Universitat Politècnica de València. The study consisted of the evaluation of 108 color pairs painted on physical cardboards, rated by 26 female students (average age 26.5), under natural lighting conditions, and using the Natural Color System (NCS) Color Atlas for the color match. Results indicate that induced colors have lower NCS blackness compared with nominal ones, and slightly higher or no NCS chromaticness shift. Nominal colors with low chromaticness exhibit an important hue induction effect and tend to shift to a hue that is located opposite to that of the background color in the NCS color circle, this effect being larger when the background has a *warm* color. The induction effect is larger when ornamental elements and background have similar nominal NCS blackness, and different nominal NCS chromaticness,with nominal hue difference no significant in the induction effect. The colors of ornamental elements that entailed greater induction were those with the lowest NCS chromaticness, and in the case of the background color, those with the highest chromaticness.

KEYWORDS

architecture, induction, restoration, simultaneous contrast, Valencia

JEL CLASSIFICATION

L74, O18, R58, R11

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
© 2023 The Authors. Color Research and Application published by Wiley Periodicals LLC.

1 | INTRODUCTION

1.1 | The Color Research Group in Architecture at Universitat Politècnica de València

Color in architecture has been frequently underestimated, possibly due to a misunderstanding of its role in the so-called Modern Movement, which proposed a radical renewal of formal architectural principles in the 1920s. The image of a white, abstract, and conceptual architecture was a distorted ideological reconstruction of modern avant-garde architecture. In Spain, this biased vision of the role of color in modern architecture was extrapolated to the historic city centers. The consequence was a generalized process of urban degradation and building substitution that would only be reversed at the beginning of the 1980s with democracy and citizen participation.

From this moment on, it was necessary to generate new methodologies to evaluate the architecture of the Spanish historic city centers and to set the intervention criteria to recover their urban image. It is within this framework that in 1991 the *Grupo de Investigación del Color en Arquitectura* (GICA) of the *Universitat Politècnica de València* (UPV) was founded, with a team of academics in Architecture and Fine Arts, led by Professor Ángela García-Codoñer. The bases of the GICA-UPV color restoration methodology during these 30 years have been: (1) A deep historic analysis of the cities, aimed at understanding the original conditions of the buildings and the chromatic and material culture prevailing at the time of their construction; (2) The use of reliable laboratory analysis of the materials and pigments, to determine construction techniques that effectively replicate the material characteristics of historic buildings; (3) A typological analysis of existing buildings and determination of the specific chromatic ranges for each type and neighborhood, preserving the complexity of historic cities and avoiding a false simplifying homogeneity; and (4) A wide dissemination activity in the scientific field, and also among the general population, to familiarize the residents with the cultural richness linked to the colors of the historic scene.

In these 30 years, the GICA-UPV has developed different projects: (1) Comprehensive color plans for the historic city centers of cities such as Valencia, Cartagena, Ontinyent, Segorbe, Burriana; (2) Chromatic regulations to avoid distortions in the urban scene; (3) Color studies in areas with high heritage value, such as the Old Square in Havana (Cuba), the *Rua da Junqueira* in Lisbon, or the Leprosery of St. Francisco de Borja in Fontilles (Alicante), among many others; (4) Color interventions in more than 30 protected buildings, ranging from those declared Sites With Cultural Interest, to more modest private buildings. At the same time, several books have been published, with national and international editorials, and the scientific results have been presented at international *fora*, with more than a hundred communications and papers.

1.2 | Figure and background colors on the facades of historic buildings

The formal composition of the facades of historic architecture is directly related to the circumstances of when the building was erected. The economic situation, the social relationships or the stylistic trends of the time, characterize architecture. In this sense, in the historic city center of Valencia, we can group the facades into several typologies studied in depth by the GICA-UPV such as artisan, classicist, eclectic, modernist, and so forth.[1] These typologies have particular formal characteristics and thus specific color ranges. Nevertheless, the compositions of these facades have common features, all of which contain large painted wall surfaces, with smaller ornamental elements superimposed on them: cornices, moldings surrounding doors and windows, pilasters, corbels, and so forth. It is normal that the chroma of the ornamental elements is lower than the background color, their value medium, and appear in a light brownish/gray color. Generally speaking, ornamental elements attempted to mimic the colors of the local stones, with the aim of bringing some magnificence to the buildings. On the other hand, the background color, or main color of a building, was traditionally linked to the mineral pigments that were locally available, being more chromatic and slightly darker than the ornaments. Colored plasters were the most economic and readily available means to protect the walls from the harshness of the weather conditions and to dignify architecture.

Unfortunately, there are still professionals who forget the distinction between ornaments and background during the restoration of a historic facade, and paint the whole building in one simple color, white or gray, with the excuse of a misunderstood modern trend. Monochromatic facades provide a wrong interpretation of historic architecture, in which color was displayed for a better expression of the formal composition of the facade.

This was the case of the *Palacete Burgos*, a private dwelling built in Valencia in 1921 by architect Javier Goerlich, that had been painted monochromatic in a previous and inappropriate architectural intervention. When the GICA-UPV was asked to make the color restoration in 2020, remains of different colors in numerous areas of

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

the facades were found. After a color analysis in laboratory, the GICA-UPV opted to recover the original polychromy, the one corresponding to the color characteristics of the eclectic Valencian architecture (Figure 1). Nevertheless, during the restoration process of this facade, the colors selected for the ornamental elements seemed different on the painted facade, surrounded by the background color, compared with those same colors observed in isolation on the color chart, what is a common occurrence. Different factors influence this shift in color perception, but the color induction effect is particularly important. To solve this problem, professionals usually apply color samples directly on the facades and make the selection onsite. This can be a difficult, time-consuming task and requires many attempts to achieve an adequate result.

As a result, it is important to study the influence of the color induction effect of background colors on the perception of the colors of ornamental elements, specifically for the color palette of the historic city center of Valencia. This will allow to predict the shift of the colors of the ornamental elements on the facades, when compared with their observation in isolation.

1.3 | The problem of color induction in architecture

The perception of a uniform color in urban context is influenced by multiple factors, including lighting, observation distance, surface extent, object geometry, and so forth.[2(sec3)] One of the most widely known and studied phenomena that influence the perception of a color in its context is simultaneous contrast, also known as color induction. As a result of this effect of chromatic interaction, "a color will be seen differently depending on the influence of the color of the surrounding area."[3(p480)] The appearance of a sample color observed in isolation (*nominal color*), will be seen differently (*induced color*), since it is influenced by the surrounding color (*inducing color*).

There is no consensus regarding the causes of the phenomenon of color induction nor about the extent of the changes perceived by an average observer. However, there are several color appearance models and theories that try to explain, predict and measure chromatic induction, such as the Hunt Model,[4(p225)] the Kirschmann's laws, the *direction law* proposed by Ekroll and Faul,[5] and the *complementary law*. *Kirschmann's fourth law* describes the relationship between the magnitude of simultaneous contrast and the saturation of the surrounding color, stating that "the level of contrast between a color and a gray of the same lightness grows with the saturation of the inducing field,"[6] but recent research demonstrate that "the form of the relationship between simultaneous color contrast and inducer saturation depends on the method of measurement."[7] The *direction law* affirms that the perceived color of any element set over a uniform surrounding color, moves away from the color of the surrounding along the path of the line plot between the surrounding color and its own.[5] This model does not provide the magnitude of this change, but only the direction. Something similar is indicated with the *complementary law*, which establishes that the change in the perceived color moves parallel to the line that unites the surrounding color and the neutral point of the CIE chromaticity diagram.

Of special interest is the experiment by Ratnasingam and Anderson conducted in the School of Psychology of the University of Sydney.[8] They developed and tested a method for assessing simultaneous contrast, while avoiding the methodological issues that arise with nulling and matching experiments and diminishing the contribution of temporal adaption to the results. They demonstrated that the perceived difference, for any randomly chosen

FIGURE 1 Left: Exterior of *Palacete de Burgos* (1921), an eclectic building by architect Javier Goerlich Lleó, Valencia (Spain). Photo August 2020. Right: Exterior after restoration of the original colors by GICA-UPV, with the grayish color of ornamental elements emphasized on the ocher background; architectural project by Javier Hidalgo. Photo: 2021.

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

surroundings, increases when the sample is placed on the line that unites both surroundings in the color space; at the same time, the induction magnitude is larger when the sample and surrounding colors share the same hue.

In the field of architecture and design, many specialists studied the effect of simultaneous contrast and the relativity of color appearance depending on the context. Of note is the artistic and theoretical works by Joseph Albers, particularly his book *Interaction of Color*,[9] first published in 1963, an essential reference on color theory for architects and designers (Figure 2). Subsequent specialists continued the research of color interactions in architecture[10] and current architectural firms continue working with the artistic possibilities of such color interactions in interior architecture or urbanscape, such as the German firm Sauerbruch Hutton Architects.[11] A remarkable color induction effect can be experienced in the restaurant Red-Light Yokohama in Kanagawa (Japan, 2010), by Yasutaka Yoshimura Architects,[12] in which visitors can observe an induced red color in a completely white room.

2 | OBJECTIVES

As indicated earlier, in the restoration of the facades of historic architecture, it is usual to find remnants of more than one color of paint and the use of polychromy to distinguish ornamental elements from the large wall surface that serves as a background. As researched by the GICA-UPV color group, in the case of the colors of Valencia's historic city center, ornamental elements tended to be neutral colors similar to sandstones (with low chromaticness and middle blackness) surrounded by more vivid colors (with higher chromaticness and blackness). Because of the characteristics of these color ranges, it is usual that the colors of the ornaments are perceived differently on the painted facade when surrounded by the background color, compared with those same colors observed in isolation on the color chart during the restoration process. Instead of the perception of a neutral earthy color, similar to local sandstone colors, some unpleasant effects may occur of color shifts into dull bluish or pinkish grays. Several factors influence this shift in color perception. However, it is the color induction effect that is particularly important, which is the influence of the color of the surrounding area on the perception of an ornamental color. To solve this during the restoration process, professionals apply samples of colors directly on the facades and conduct a visual adjustment that many times is difficult, time-consuming and requires several attempts to achieve a good result. Therefore, the effect of color induction in architectural restoration remains a critical issue.

For these reasons, the objective of this research is to predict how the nominal color of an ornamental element would be perceived when set on the facade of a building, surrounded by different background colors, due to the color induction effect, and considering the colors of traditional architecture of the historic city center of Valencia. The objective is to study the induction effect on the ornamental elements considering the three perceptual variables that describe a color in Natural Color System (NCS) independently (hue, blackness, chromaticness), and holistically as a *global induction effect* (hue + nuance). Another objective is to assess the influence that the similarity/difference in NCS attributes between ornamental colors and background colors have in the induction of the ornamental colors. Finally, the objective is to identify those color pairs from the traditional color palette of Valencian architecture with more induction effect, the background colors that entail more induction, and the ornamental colors that go through greater color shifts.

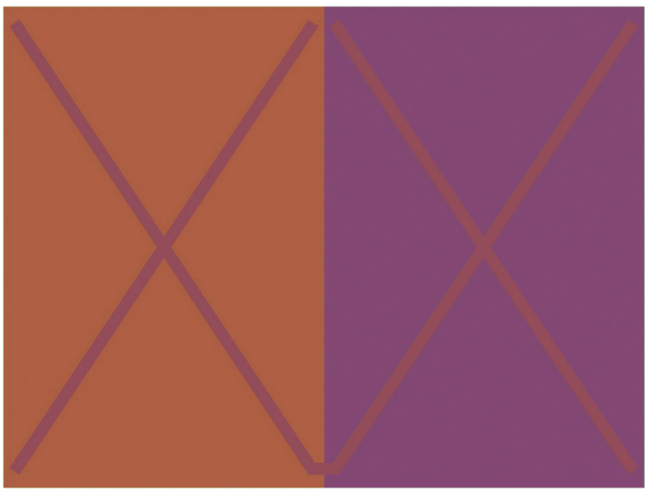

FIGURE 2 Example of color induction after Joseph Albers' exercises from *Interaction of Color*, Juan Serra, 2022. The interior double Xs have the same nominal color but seem different. Moreover, because of color induction, the X on the left is similar to the background on the right, and the X on the right is similar to the background on the left.

3 | MATERIALS AND METHODS

For the development of the study, some colors belonging to the color palette of the historic city center of Valencia and studied by the GICA-UPV were selected. The criteria for the color selection were to have a representation of some of the most common colors in the different neighborhoods, and to have a wide variety of different

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

hues in the color circle. A total of 21 colors were selected, 9 colors that were commonly used for the ornamental elements or figure colors, and 12 colors that were used for the surfaces of the wall or background colors (Table 1). In a light box illuminated with a D65 standard lighting, the 21 selected colors were denoted in NCS, observing each color in isolation, and matching with a NCS Color Pin and a double check with the NCS Color Atlas by two experts. The notation of these colors in isolation was labeled *NCS nominal color*.

These colors were displayed uniformly on the surface of cardboards using exterior paints provided by the Valencian company ISAVAL. The dimensions of the cardboards for the background colors were 300 × 150 mm and the dimensions of the cardboards for the figure colors were 75 × 50 mm. Every figure color was placed on the center of every background color obtaining a total amount of 108 color pairs that were randomly distributed on nine panels with 12 color pairs each (Figure 3).

The color panels were displayed vertically in an exterior terrace placed at the Valencia School of Architecture. The exterior terrace was covered on the top and two sides and had two open sides oriented to south and west, in such a way that the vertical wall received natural lighting but not direct sunlight. The experiment was developed on January 18, at 14:58:58 (time zone GMT+1).

The natural lighting on the cardboard surface was measured with a spectrometer Lighting Passport TM (©2021 Asensetek Canada Inc.). The lighting parameter analysis report indicated an average Correlated Color Temperature of 6940 K, and an average Color Rendering Index of 94, which were considered adequate lighting parameters for a color evaluation with natural lighting (Table 2).

The color pairs were evaluated by 26 female students of architecture at Master Level, aged between 22 and 36 (Average Age 26.5; Standard Deviation SD = 3.6), who reported no color blindness after a general evaluation with a free online color blindness test, based on the Farnsworth Munsell Hue Test.[13] Each observer was invited to evaluate two panels with 12 color pairs each, so every pair was evaluated by five different people. For each color pair, the observer was asked to match the figure color with the adequate color of the NCS Color Atlas. The color pairs were displayed vertically at two meters of distance from the observer, who was standing. The NCS Color Atlas was displayed on a table in front of the observer, and was observed under approximately similar lighting conditions of the samples. Every observer had a gray cardboard mask (NCS S 5000-N) to isolate the colors of the NCS Atlas and observe them individually. A gray background that is usual in color induction studies, was selected instead of the white, normal for NCS color selection, considering that gray might reduce the effect of blackness induction in the color selection. With the help of an online questionnaire in Google Forms, participants wrote down the colors in NCS and an anonymized database in Microsoft Excel format was obtained and studied with IBM SPSS® software.

TABLE 1 *NCS nominal colors* of the 9 colors selected for the ornamental elements and the 12 colors selected for the backgrounds, from the color palette of the historic city center of Valencia.

Ornamental elements nominal colors	Background nominal colors
1. NCS S 3502-Y	01. NCS S2060-Y10R
2. NCS S 3010-Y10R	02. NCS S 3050-Y20R
3. NCS S1010-Y20R	03. NCS S 2040-Y30R
4. NCS S 2010-Y30R	04. NCS S 3040-Y40R
5. NCS S 3020-Y40R	05. NCS S 4040-Y50R
6. NCS S 3005-Y50R	06. NCS S 4040-Y60R
7. NCS S 2020-Y60R	07. NCS S 4050-Y70R
8. NCS S 2010-B10G	08. NCS S 3010-Y80R
9. NCS S 2010-G90Y	09. NCS S 2020-B90G
	10. NCS S 0515-G20Y
	11. NCS S 2020-G30Y
	12. NCS S 3030-G90Y

Note: Notation in Natural Color System.

3.1 | Description of the variables

The observed figure color in NCS was labeled *induced color* since it was evaluated in interaction with the surrounding background color, and therefore was subject to color induction. The effect of the color induction was evaluated as the difference between the *nominal color* and the *induced color* in NCS.

The NCS notation of every color was segmented into the three variables of the system, corresponding to blackness [0, 100], chromaticness [0, 100], and hue. The NCS hue was converted into angular degrees following the centesimal system with values between 0 and 400, with 0 corresponding to Red, 100 to Yellow, 200 to Green, 300 to Blue, and 390 to R10B.

The *average induced color* in every color pair is obtained as the arithmetic average of the observations of such a figure color on such a background color (Section 4.1). The average induced color had three variables: blackness, chromaticness and hue. To calculate the average blackness, the result was set as

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

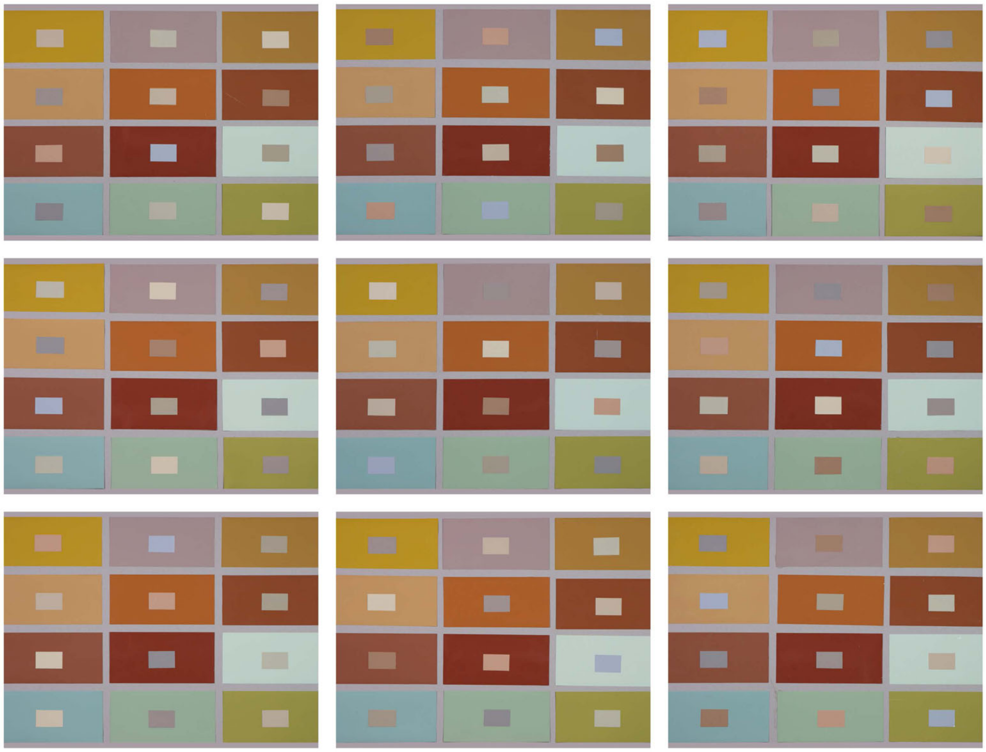

FIGURE 3 The nine figure colors were tested on 12 background colors, resulting in 108 color pairs randomly distributed on nine panels.

TABLE 2 Lighting parameter analysis report.

	CIE_x	CIE_y	CIE_u′	CIE_v′	CCT	Duv	CRI (Ra)	CRI (Re)
Measure 1	0.3031	0.3146	0.1965	0.4590	7240 K	0.0008	96	94
Measure 2	0.3115	0.3212	0.2000	0.4639	6641 K	−0.0002	95	94
Range	0.0084	0.0065	0.0034	0.0049	600 K	0.0010	1	1
Average	0.3073	0.3179	0.1982	0.4614	6940 K	0.0003	96	94

$Blck_{average} = (Blck_1 + Blck_2... + Blck_n)/n$; for chromaticness average $Chrm_{average} = (Chrm_1 + Chrm_2... + Chrm_n)/n$; and for hue average $Hue_{average} = (Hue_1 + Hue_2... + Hue_n)/n$, being n the total amount of observations for each figure color onto a given background color.

The *induction effect* in every color pair was obtained as the difference between the *average induced color* and the *nominal color*, for such a color figure observed onto a given color background (Section 4.2). The *induction effect* was calculated with four variables: blackness, chromaticness, nuance (blackness + chromaticness) and hue. We did not quantify the variable NCS whiteness, but it has a linear relationship with the nuance, being whiteness = 100-nuance. For the calculation of blackness difference, the result was set as $Blck_{difference} = Blck_{induced} - Blck_{nominal}$; for chromaticness difference $Chrm_{difference} = Chrm_{induced} - Chrm_{nominal}$; for hue difference as $Hue_{difference} = ABS\ (hue_{induced} - hue_{nominal})$; and for nuance difference $Nuan_{difference} = ABS\ (Blck_{difference}) + ABS\ (Chrm_{difference})$, being ABS the absolute value of the numbers.

The *influence of the similarity/difference between figure and background nominal colors in the induction effect* was evaluated (Section 4.3). With the help of IBM SPSS® software, an analysis of variance with Pearson correlation for the NCS variables of hue, blackness and chromaticness, was developed.

With the aim to order the 108 color pairs, from those with the greatest induction effect, to those with the least, it was necessary to group together the induction effect corresponding to the independent variables blackness, chromaticness and hue, and with the difficulty that these three variables have a different range, [0–100] for blackness and chromaticness, and [0–400] for hue. The solution was to divide the color pairs into four groups according to their *nuance difference*, giving a value of +4 to those in the first quartile and therefore with greater nuance difference, and respectively +3 to those in the second quartile, +2 in the third, +1 in the fourth, and 0 to those with no nuance difference between nominal and induced color. The same was conducted for the

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

hue difference, giving a value of +4 to those in the first quartile and therefore with greater hue difference, and respectively +2, +1, and 0 to those with no hue difference between nominal and induced color. The addition of these two values that depend on the *nuance* and *hue difference* positions, allowed to obtain a *global induction effect* with a value between 0 and 8 for each color pair, and to order the 108 color pairs from those with the greatest induction effect to those with the least (Table A1). A particular study of those color pairs that entailed greatest induction effect (those with a *global induction effect* between 6 and 8) was developed, plotting the results on the NCS color circle and on the NCS nuance triangular figure (Section 4.4).

4 | RESULTS

4.1 | Average induced color

The average induced colors of the ornamental elements were calculated for the three NCS attributes blackness, chromaticness and hue (Table 3). Regarding *blackness*, the nine figure colors have nominal NCS blackness that ranges from 10 to 35, and their average induced NCS blackness from 5 to 27 in the 108 color pairs. The SD of the average induced NCS blackness ranges from 0 to 14, and just in 14 cases (13%) NCS blackness SD is ≥10, which is the minimum blackness distance between adjacent standard colors in the NCS Atlas. In general, induced colors have lower NCS blackness compared with nominal and this effect is larger in darker nominal colors, those with higher blackness. Moreover, the highest SD, and so the largest dispersion in the evaluation of induced blackness, is produced for the figure colors with higher nominal blackness (Table 3).

The nine figure colors selected have nominal NCS chromaticness from 5 to 20, and the average induced NCS chromaticness ranges from 4 to 35, in the 108 color pairs. The SD of the average induced NCS chromaticness ranges from 1 to 17, and just in seven cases (6.48%) NCS chromaticness SD is ≥10, which is the minimum chromaticness distance between adjacent standard colors in the NCS Atlas. In general, induced colors have slightly higher NCS chromaticness or no chromaticness shift compared with nominal, and this effect is greater in bolder nominal colors, those with higher chromaticness. The highest SD, and so the greatest dispersion in the evaluation of chromaticness, is produced for the figure colors with higher nominal chromaticness (Table 3).

The nine figure colors selected have nominal NCS hue placed between 40 and 290, and the average induced NCS hues from 17 to 330, in the observations of the 108 color pairs. The SD of the average induced NCS hue, ranges from 0 to 190 steps in NCS color circle. In 12.9% ($n = 14$) of the 108 color pairs, the SD of average induced hue has been 0 hues; in 55.5% ($n = 60$) SD ∈ [10,40]; in 13.8% ($n = 15$) SD ∈ [50,80]; 12.9% ($n = 14$) SD ∈ [90130], and in 4.6% ($n = 5$) SD ∈ [140,190]. Therefore, there is a great dispersion in the answers of observers when evaluating the NCS hue of figure colors, particularly for color NCS S 3005-Y50R (Table 3).

4.2 | Induction effect

The induction effect in every color pair has been calculated as the difference between the average induced color

TABLE 3 Nominal NCS blackness, chromaticness and hue angle, together with the average induced NCS blackness, chromaticness and hue angle, with indication of the standard deviation, for the nine figure colors.

Figure color [NCS]	Nom. Black (%)	Ind. Black (%)	Diff. Black. (%)	SD. Black (%)	Nom. Chr. (%)	Ind. Chr. (%)	Diff. Chr. (%)	SD Chr. (%)	Nom. Hue [0,400]	Ind. Hue [0,400]	Diff. Hue [0,200]	SD Hue [0,400]
S 3502-Y	35	22.7	−12.2	**9.17**	2	7.42	5.42	3.67	100	203	103	**130**
S 3010-Y10R	30	14.5	−15.5	5.83	10	10.42	0.42	4.75	90	187	97	**177**
S1010-Y20R	10	6.2	−3.7	2.67	10	9.83	−0.17	4.17	80	129	49	85
S 2010-Y30R	20	8.2	−11.7	3.25	10	11.33	1.33	4.67	70	113	43	58
S 3020-Y40R	30	24.1	−5.9	**9.25**	20	17.25	−2.75	**6.25**	60	150	107	193
S 3005-Y50R	30	21.2	−8.8	**8.58**	5	7.00	2	3.08	50	167	190	**183**
S 2020-Y60R	20	7.8	−12.2	3.08	20	20.50	0.5	**8.50**	40	91	51	128
S 2010-B10G	20	6.6	−13.4	2.83	10	14.33	4.33	6.08	290	235	54	47
S 2010-G90Y	20	7.7	−12.2	3.33	10	8.75	−1.25	3.42	110	174	64	93

Note: Bold indicates those figure colors with a greater dispersion in the assessment.

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

and the nominal color, for such a color figure observed onto a given color background. The induction effect has been calculated separately for blackness, chromaticness, hue, nuance, and holistically as a *global induction effect*.

The NCS blackness induction ranges from 0 to 24, in the observations of the 108 color pairs. A total of 65.7% ($n = 71$) figure colors, have an induction effect ≥10 NCS blackness, which is the minimum to have a shift between adjacent standard colors in NCS atlas. On the other hand, the NCS chromaticness induction ranges from 0 to 21, in the observations of the 108 color pairs. Just 7.4% ($n = 8$) figure colors, have an induction effect ≥10 NCS chromaticness, which is the minimum to have a shift between adjacent standard colors in NCS atlas. Therefore, the induction effect is more important in the evaluation of the NCS blackness of a figure color and not in the NCS chromaticness.

The NCS nuance (blackness + chromaticness) can have a value from 10 to 90 in NCS atlas, with a maximum nuance difference possible of 80. The Nuance Induction ranges from 0 to 31 in the observation of the 108 color pairs. In 21.3% ($n = 23$), Nuance Induction ∈ [0–9]; in 56.5% ($n = 61$) Nuance Induction ∈ [10–19]; and in 22.2% ($n = 24$) Nuance Induction ∈ [20–31]. Considering that a color shift in NCS Nuance between adjacent standard colors needs a minimum value of 10, Nuance Induction was relevant in most of the color pairs (78.7%). It is interesting to remember that nuance is directly related with NCS whiteness, being whiteness = 100-nuance.

The NCS hue Induction can range from 0, for colors with the same hue, to 200, for opponent colors in the color circle, and being 10 steps the distance between adjacent hues in the standard NCS color circle that is, R to Y90R. In the observations of the 108 color pairs, in 21.3% ($n = 23$) the NCS hue difference is 0, and so there is no Hue Induction; in 47.2% ($n = 51$) Hue Ind ∈ [10,50]; in 11.1% ($n = 12$) Hue Ind ∈ [60,100]; 7.4% ($n = 8$) Hue Ind ∈ [110,150], and in 12.9% ($n = 14$) Hue Ind ∈ [160,200]. Therefore, there is an important induction effect in the hue of the figure colors.

The calculation of the *global induction effect* is a holistic assessment that includes simultaneously the Nuance Induction and the Hue Induction and permits to order the 108 color pairs from those with the highest induction effect to those with the lowest. As explained earlier (Section 3), the global induction depends on quartiles and can have a value from 0 to 8 for each color pair (Table A1). The sum of the individual *global induction effect* of a given figure color observed onto the 12 background colors, provides a possible value between 0 and 96, and allows to categorize the nine figure colors in order from most to least induction effect (Table 4). The figure colors with the greatest overall induction in our research is NCS S 3502-Y, NCS S 3005-Y50R, and NCS S 3010-Y10R. These figure colors correspond with the colors which are closer to gray, and so with lower NCS chromaticness. On the other side, the sum of the *global induction effect* of the nine figure colors observed onto a given background color, provides a possible value between 0 and 72, and allows to order the 12 background colors from those who entail most to least induction effect (Table 4). In our research, the background colors which entail the greatest overall induction is NCS S 2060-Y10R and NCS S 2040-Y30R. These correspond to background colors that have low blackness and high chromaticness.

TABLE 4 Left: The 12 background colors in order from those that entail most to least induction. Right: The nine figure colors corresponding to ornamental elements in order from the greatest to the least induction.

NCS background colors	Global induction [0, 72]	NCS figure-colors of ornamental elements	Global induction [0, 96]
NCS S2060-Y10R	42	NCS S 3502-Y	69
NCS S 2040-Y30R	41	NCS S 3005-Y50R	64
NCS S 2020-G30Y	39	NCS S 3010-Y10R	53
NCS S 2020-B90G	35	NCS S 2010-G90Y	44
NCS S 3010-Y80R	34	NCS S 2010-B10G	44
NCS S 3040-Y40R	34	NCS S 2020-Y60R	38
NCS S 4040-Y60R	34	NCS S 3020-Y40R	32
NCS S 3030-G90Y	33	NCS S 2010-Y30R	31
NCS S 3050-Y20R	32	NCS S1010-Y20R	25
NCS S 4040-Y50R	30		
NCS S 4050-Y70R	30		
NCS S 0515-G20Y	25		

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

4.3 | Influence of the similarity/difference between figure and background nominal colors in the induction effect

The objective of this analysis is to find out to what extent, the induction effect is influenced by the similarity/difference between figure and background nominal colors for the three NCS variables: hue, blackness and chromaticness (Table 5).

Results of the Pearson correlation indicate that there is no significant association between the induction effect and the nominal hue difference of figure and background. Therefore, in our experiment, if figure and background have similar hue, it does not entail a larger or lower induction effect. Nevertheless, results of the Pearson correlation indicate that there is a low significant negative association between induction effect, and the blackness difference figure background ($r[106] = -0.199$ $p = 0.039$). Therefore, when nominal blackness difference between figure and background is larger, the induction effect is lower. In other words, if figure and background have similar NCS blackness, the induction effect will be larger.

Regarding chromaticness, results of the Pearson correlation indicate that there is a low significant positive association between induction effect and the nominal chromaticness difference figure-background ($r[106] = 0.241$ $p = 0.012$). Therefore, when chromaticness difference between figure and background is larger, the induction effect is larger. In other words, if figure and background have similar NCS chromaticness, the induction effect is low.

4.4 | Study of the color pairs with more induction

The 18 color pairs with the greatest induction effect in our research, is indicated in Table 6. They all correspond with a *global induction effect* between 6 and 8. The nominal figure colors belonging to these pairs are those with lower NCS chromaticness, and therefore closer to a neutral gray, with exceptions in four cases. For a visual interpretation of the induced figure color, Table 6 shows the notation of the closest NCS standard color, while the exact values are indicated numerically in Table A1. A particular study for these colors is developed, plotting the results on the NCS color circle and on the NCS nuance triangular figure (Figure 4).

The observation of Figure 4 indicates that, regarding the analysis of the NCS color circle, there is a relevant hue shift between nominal and perceived color that follows the direction of the line that connects the background color and the nominal figure color. The induced color tends to be distant from the background color, shifting to a color with slightly more NCS chromaticness (10%) and to a hue that is opponent in the color circle, note that in Figure 4 (left) the "arrows" tend to be centrifugal. This hue shift toward opponent hues is more evident in colors observed onto *warm* backgrounds (Y10R to Y40R) that tend to acquire a *cool* induced hue (B to G40Y). Curiously, in our experiment, when the background is *cool* (B90G to G30Y) the induced hue tends to be also *cool*.

Regarding the analysis of the NCS nuance triangle, we observe that the induced figure colors tend to have lower NCS blackness compared with nominal, and to have no chromaticness shift, note that the "arrows" are vertical. The reduction in NCS blackness is 10% to 15%.

5 | CONCLUSIONS AND DISCUSSION

In the restoration of historic facades, specialists need to tackle the problem of colors that are observed slightly differently on a facade than isolated. This issue is particularly critical in the observation of the colors of ornamental elements, which usually have neutral colors, surrounded by an extension of more chromatic colors on the wall surfaces, and therefore affected by the color induction phenomenon. For this reason, we conducted an experiment to evaluate the difference between nominal and induced colors of ornamental elements observed on background colors, considering the historic color palette of Valencia,

TABLE 5 Pearson correlation between Induction Effect and the difference figure-background nominal colors for the three NCS variables

		Induction Effect	Diff Fig-Back Nom. Hue	Diff Fig-Back Nom. Blackness	Diff Fig-Back Nom. Chromaticnes
Induction Effect	Pearson Correlation	1	−0.049	−0.199*	0.241*
	Sig. (2-tailed)		0.614	0.039	0.012
	N	108	108	108	108

*Significant levels for the Pearson rank coefficient are indicated at $p < 0.05$ level.

TABLE 6 The 18 color pairs with more *global induction effect*, indicating NCS standard notation for the background color, nominal, and induced figure color.

NCS Standard background color	NCS Standard nominal figure color	NCS Standard induced figure color
2060-Y10R	2010-G90Y	1010-B70G
2040-Y30R	3502-Y	2010-B30G
0515-G20Y	3502-Y	3010-B50G
3030-G90Y	3005-Y50R	2502-G
2060-Y10R	3005-Y50R	1005-G10Y
3040-Y40R	3005-Y50R	1502-B
2020-G30Y	3502-Y	2005-R70B
3010-Y80R	3005-Y50R	2005-B80G
3030-G90Y	3502-Y	2005-B50G
2040-Y30R	3010-Y10R	2010-B90G
2060-Y10R	3502-Y	2010-R90B
2060-Y10R	3010-Y10R	0507-G
3010-Y80R	3502-Y	2005-R80B
3050-Y20R	3502-Y	2004-R90B
2040-Y30R	3020-Y40R	2010-G30Y
3040-Y40R	3502-Y	2010-B
2020-B90G	3005-Y50R	2020-B40G
2020-G30Y	3005-Y50R	2010-G40Y

Note: The average induced color is represented by the closest standard color from the NCS Atlas 2050.

studied by the Color Research Group GICA-UPV. The study included the evaluation of 108 color pairs painted on physical cardboards, evaluated by 26 females (Avr. age 26.5; SD = 3.6), under natural lighting conditions, and using the NCS color atlas for the color match.

Some limitations need to be indicated that should be considered in the application of the results to other architectural conditions different to those of the experiment, particularly in relation to the homogeneity of observers and the lighting conditions of the assessment. All participants were university students, with similar age, and a similar cultural background. Therefore, it has not been possible to demonstrate if these findings are consistent for other observers, with distinctive characteristics. Similarly, it is expected that the observation of architectural facades at street level, with a continuous shift in light depending on the time, date, weather conditions, solar orientation, presence of cast shadows, together with other aspects such as the reflected light from the surroundings, observation distance, scale of the building, and so forth, might entail slightly different results. Our experiment is framed within the observation conditions indicated.

The results of the study indicate that, in general, induced colors have lower NCS blackness compared with nominal, and slightly higher or no chromaticness shift. Therefore, the induction effect is more important in the evaluation of the NCS blackness than in the chromaticness. When plotted on the NCS nuance triangle, the "arrows" tend to be vertical. Nuance Induction was

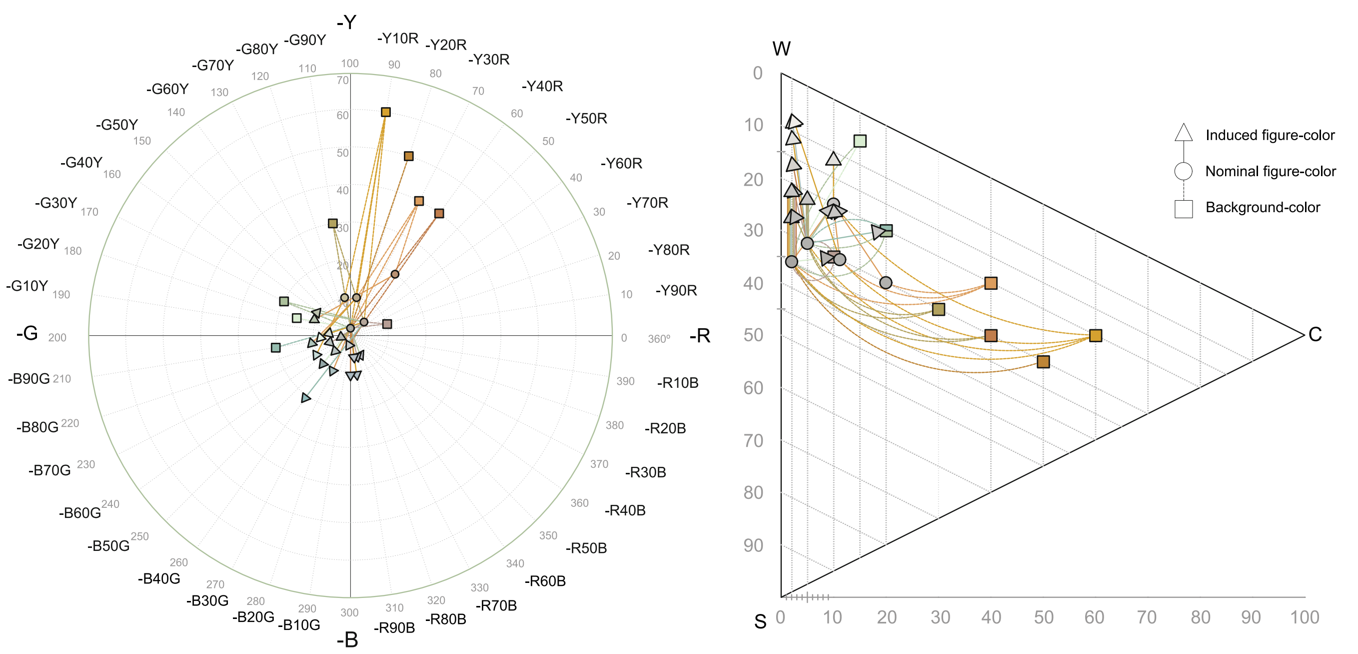

FIGURE 4 The 18 color pairs with more induction plotted on the NCS color circle (left), and the NCS nuance triangle (right).

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

relevant in most of the color pairs (78.7%), with one to three color shifts in the NCS nuance triangle. Being the variable nuance directly related with NCS whiteness, results indicate that whiteness induction was relevant for most of the color pairs.

In this research, there is evidence of an important induction effect in the hue of most of the figure colors (78.7%), this effect being bigger in nominal colors closer to gray, those with low chromaticness, observed onto backgrounds with much higher chromaticness. This result is somehow coherent with *Kirschmann's fourth law*, indicating that the induction effect between a color and a gray of the same lightness grows with the saturation of the inducing field.[7] It is important to note that saturation in NCS is directly proportional but not the same as chromaticness, being saturation (m) the relationship between the chromaticness (c) and whiteness (w) of a color, $m = c/(c + w) = c/(100\text{-blck})$.[14(p188)]

In the NCS color circle, the induced color tends to distance from the background color, shifting to a color with slightly more NCS chromaticness and to a hue that is opposite in the color circle, the "arrows" tend to be centrifugal. This finding is coherent with the *direction law*, which affirms that in the case of contrast, the perceived color of any element set over a uniform surrounding color, moves away from the color of the surrounding along the path of the line plot between the surrounding color and its own. This hue shift toward opposite hues is more evident in

TABLE 7 Summarize of the findings.

Color variable	Difference induced-nominal (unit)	Results
Blackness	−6 to −15 (%)	• Induced colors have lower NCS blackness compared with nominal and this effect is greater in darker nominal colors, those with higher blackness • 65.7% ($n = 71$) figure colors, have an induction effect ≥10% NCS blackness
Chromaticness	−1 to 5 (%)	• Induced colors have slightly higher NCS chromaticness or no chromaticness shift compared with nominal and this effect is greater in bolder nominal colors, those with higher chromaticness • 7.4% ($n = 8$) figure colors, have an induction effect ≥10% NCS chromaticness
Nuance	0 to 31 [0, 80]	• Induced colors have significant NCS nuance shift in most of the cases: 22.2% ($n = 24$) have a nuance shift between 20% and 31%, with 2 or 3 steps in NCS triangle; 56.5% ($n = 61$) have a nuance shift between 10% and 19%, with one step in NCS triangle
Hue	0 to 230 [NCS Hue steps]	• Induced colors have an evident hue shift compared with nominal and this effect is greater in nominal colors closer to gray, those with low chromaticness • Just 21.3% ($n = 23$) had no hue shift
Nominal hue difference figure-background	Global induction	• No significant association. If figure and background have similar nominal hue, it does not entail a greater or lesser induction effect
Nominal blackness difference figure-background	Global induction	• If figure and background have similar nominal NCS blackness, the induction effect is greater
Nominal chromaticness difference figure-background	Global induction	• If figure and background have different nominal NCS chromaticness, the induction effect is bigger
All color variables together	Global induction	• In the NCS color circle, the induced color tends to distant from the background color, shifting to a color with slightly more NCS chromaticness (≈10%) and to a hue that is opponent in the color circle, the "arrows" tend to be centrifugal. As expected, the induction effect is of contrast, not of assimilation • In the NCS nuance triangle, induced figure colors tend to have lower NCS blackness compared with nominal, but not significant chromaticness shift, the "arrows" tend to be vertical • The figure colors affected by greater induction is those with the lowest chromaticness: NCS S 3502-Y and NCS S 3005-Y50R • The background color that entails greater induction is that with highest chromaticness: NCS S2060-Y10R

colors observed onto *warm* backgrounds (Y10R to Y40R) that tend to acquire a *cool* induced hue (B to G40Y). Curiously, in our experiment, when the background is *cool* (B80G-G30Y) the induced hue tends to be also *cool*.

Regarding the Influence of the similarity/difference between figure and background nominal colors, the induction effect is bigger when figure and background have similar nominal NCS blackness, and different nominal NCS chromaticness.

If figure and background have similar hue, it does not entail a bigger or lower induction effect. The figure colors affected by greater induction is those with the lower chromaticness: NCS S 3502-Y and NCS S 3005-Y50R. The background color that entails greater induction is that with highest nominal chromaticness: NCS S2060-Y10R. Table 7.

ACKNOWLEDGMENTS

Funding for open Access charge: CRUE-Universitat Politècnica de València. Authors are responsible for the study of historic urban colors of Valencia, the literature review, design of the experiment, selection of stimuli, data collection, analysis of results, discussion and conclusions. The authors thank the students of the subjects: "*Color y Diseño de Espacios*" belonging to the master's in advanced architecture (MAAPUD), and "Color Control for Products" belonging to the master's in industrial design (MUID) at Universitat Politècnica de València (UPV) for their participation in the experiment. Authors acknowledge Eva Prieto from Pinturas ISAVAL for their collaboration in elaborating the physical samples (https://www.isaval.es/en/). Authors thank the collaboration of PhD. Nuria Castilla (Building Technology Research Center-UPV) in the Lighting Parameter Analysis, PhD. Irene de la Torre (GICA-UPV) in the assistance to the experiment, Jay Flynn in the English linguistic supervision, and Paula Martínez-Navarro in the color selection and visual evaluations.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Juan Serra https://orcid.org/0000-0001-6171-1285
Ignacio Cabodevilla-Artieda https://orcid.org/0000-0001-7303-3899
Ana Torres-Barchino https://orcid.org/0000-0002-2117-3563
Jorge Llopis https://orcid.org/0000-0003-2939-9273

REFERENCES

[1] García Codoñer Á, Llopis Verdú J, Masiá León JV, Torres Barchino A, Villaplana GR. *El Color de Valencia: El Centro Histórico*. Excmo. Ayuntamiento de Valencia y Generalitat Valenciana; 2012.
[2] Serra LJ. *Color for Architects*. Princeton Architectural Press; 2019.
[3] Sanz JC, Gallego R. *Diccionario Del Color*. Akal; 2001.
[4] Fairchild MD. *Color Appearance Models*. 3rd ed. Wiley; 2013.
[5] Ekroll V, Faul F. New laws of simultaneous contrast? *Seeing Perceiving*. 2012;25(2):107-141. doi:10.1163/187847612X626363
[6] Kirschmann A. Ueber die quantitativen Verhältnisse des simultanen Helligkeits- und Farben-Contrastes. *Philosophische Studien*. 1891;6:417-491.
[7] Bosten JM, Mollon JD. Kirschmann's fourth law. *Vision Res*. 2012;53(1):40-46. doi:10.1016/j.visres.2011.11.007
[8] Ratnasingam S, Anderson BL. What predicts the strength of simultaneous color contrast. *J Vis*. 2017;17(2):1-17. doi:10.1167/17.2.13
[9] Albers J. *Interaction of Color*. 50th Anniversary ed. Yale University Press; 2013.
[10] Mahnke FH, Mahnke RH. *Color, Environment, and Human Response: The Beneficial Use of Color in the Architectural*. Van Nostrand Reinhold Company; 1996.
[11] Sauerbruch M, Hutton L. *Sauerbruch Hutton Archive*. Lars Müller; 2006.
[12] Yasutaka Yoshimura Architects. Red Light Yokohama; 2010. Accessed September 19, 2022 https://www.yasutakayoshimura.com/red-light-yokohama
[13] Color Blindness Test. Farnsworth Munsell 100 Hue Test; 2021. Accessed September 19, 2022 https://www.colorblindnesstest.org/farnsworth-munsell-100-hue-test/
[14] Hård A, Sivik L, Tonnquist G. NCS, Natural Color System-from concept to research and applications. Part I. *Color Res Appl*. 1996;21(3):180-205. doi:10.1002/(SICI)1520-6378(199606)21:33.0.CO;2-O

AUTHOR BIOGRAPHIES

Juan Serra, PhD. Architect, full-time Associate Professor, Sub-Dean of Research in the School of Architecture, has been Fulbright Scholar, and is member of the Color Research Group in Architecture (GICA) of the Heritage Restoration Institute at the Universitat Politècnica de València (UPV) in Spain. Dr. Serra is a specialist in color in modern and contemporary architecture. He is author of the book *Color for Architects* (PAPress, 2019) and has participated in competitive research projects about color restoration, color integration of buildings, and color in interior architecture to improve well-being and performance.

Ignacio Cabodevilla-Artieda, PhD. Architect, is Adjunct Professor at the School of Architecture, and member of the Color Research Group in Architecture (GICA) of the Heritage Restoration Institute at the Universitat Politècnica de València (UPV). His main research lines include the Architectural Heritage of

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

the former Crown of Aragon as well as color in architecture, both historic and modern.

Ana Torres-Barchino, PhD. in Fine Arts, is a full-time Associate Professor in the Department of Architectural Graphic Expression in the School of Architecture, and member of the Color Research Group in Architecture (GICA) of the Heritage Restoration Institute at the Universitat Politècnica de València (UPV) in Spain. Dr. Torres-Barchino is specialist in color analysis and recovery in architectural heritage and has participated in competitive research projects for the color restoration of urban environments and buildings in various cities, as well as color in interior architecture to improve well-being and performance.

Jorge Llopis, PhD. Architect, is Full Professor in the Department of Architectural Graphic Expression of the Polytechnic University of Valencia, and member of the Color Research Group in Architecture (GICA) of the Heritage Restoration Institute at the Universitat Politècnica de València (UPV) in Spain. His main research interests are the documentary analysis of heritage architecture, the analysis of color in historic architecture and the analysis of new architectural graphic strategies in the field of new digital architecture. Currently, he is deputy editor of the journal *EGA: Revista de Expresión Gráfica Arquitectónica*.

How to cite this article: Serra J, Cabodevilla-Artieda I, Torres-Barchino A, Llopis J. Color induction in the restoration of architecture in historic city centers. *Color Res Appl*. 2023;48(5): 497-512. doi:10.1002/col.22856

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

APPENDIX A

TABLE A1 The 108 color pairs selected for the experiment, in order from most to least *global induction effect.*

Global induction effect	Nominal background color in NCS			Nominal figure color in NCS			Induced figure color in NCS			Difference induced-nominal in NCS		
	S	C	H (Standard)	S	C	H (Standard)	S	C	H [0–400]	S	C	H [0–400]
7	20	20	G30Y	35	2	Y	23	6	330	+12	−4	+230
7	20	60	Y10R	35	2	Y	20	10	305	+15	−8	+205
7	20	60	Y10R	30	10	Y10R	7	7	203	+23	+3	+113
7	20	40	Y30R	35	2	Y	24	7	270	+11	−5	+170
7	30	40	Y40R	35	2	Y	20	6	305	+15	−4	+205
6	20	20	B90G	30	5	Y50R	23	18	260	+8	−3	+210
6	5	15	G20Y	35	2	Y	27	7	254	+8	−5	+156
6	20	20	G30Y	30	5	Y50R	18	14	155	+13	−9	+105
6	30	30	G90Y	30	5	Y50R	23	4	196	+7	−1	+146
6	30	30	G90Y	35	2	Y	24	5	247	+11	−3	+147
6	20	60	Y10R	20	10	G90Y	7	7	227	+13	+3	+117
6	20	60	Y10R	30	5	Y50R	15	4	190	+15	+1	+140
6	30	50	Y20R	35	2	Y	23	4	315	+13	−2	+215
6	20	40	Y30R	30	10	Y10R	17	7	213	+13	+3	+123
6	20	40	Y30R	30	20	Y40R	23	10	167	+8	+10	+107
6	30	40	Y40R	30	5	Y50R	17	4	302	+13	+1	+252
6	30	10	Y80R	30	5	Y50R	17	6	222	+13	−1	+172
6	30	10	Y80R	35	2	Y	18	5	320	+17	−3	+120
5	20	20	B90G	30	10	Y10R	14	10	187	+16	−0	+97
5	5	15	G20Y	30	5	Y50R	33	8	250	+3	−3	+200
5	20	20	G30Y	20	10	G90Y	6	8	172	+14	+2	+62
5	20	60	Y10R	20	20	Y60R	5	35	57	+15	−15	+17
5	30	50	Y20R	30	5	Y50R	20	6	189	+10	−1	+139
5	20	40	Y30R	30	5	Y50R	24	6	196	+6	−1	+146
5	40	40	Y50R	30	5	Y50R	18	9	106	+12	−4	+56
5	40	40	Y50R	30	10	Y10R	15	23	75	+15	−13	−15
5	40	40	Y60R	20	10	B10G	6	24	300	+14	−14	+10
5	40	40	Y60R	30	5	Y50R	23	5	220	+7	0	+170
5	40	40	Y60R	30	10	Y10R	6	8	110	+24	+3	+20
5	40	50	Y70R	30	10	Y10R	13	13	161	+17	−3	+71
5	40	50	Y70R	35	2	Y	25	23	115	+10	−21	+15
4	20	20	B90G	20	10	G90Y	7	9	174	+13	+1	+64
4	20	20	B90G	35	2	Y	26	6	203	+9	−4	+103
4	20	20	B90G	20	10	B10G	6	13	304	+14	−3	+14
4	20	20	B90G	30	20	Y40R	23	30	70	+7	−10	+10
4	20	20	G30Y	30	10	Y10R	12	7	70	+18	+3	−20
4	20	20	G30Y	20	10	B10G	5	17	300	+15	−7	+10
4	20	20	G30Y	20	10	Y30R	6	8	77	+14	+2	+7
4	30	30	G90Y	20	10	G90Y	9	10	182	+11	0	+72

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE A1 (Continued)

Global induction effect	Nominal background color in NCS S	C	H (Standard)	Nominal figure color in NCS S	C	H (Standard)	Induced figure color in NCS S	C	H [0–400]	Difference induced-nominal in NCS S	C	H [0–400]
4	30	30	G90Y	30	10	Y10R	23	7	167	+7	+3	+77
4	30	30	G90Y	20	10	Y30R	10	21	90	+10	−11	+20
4	20	60	Y10R	20	10	Y30R	6	5	82	+14	+5	+12
4	30	50	Y20R	30	10	Y10R	13	15	80	+18	−5	−10
4	20	40	Y30R	20	10	B10G	5	17	303	+15	−7	+13
4	20	40	Y30R	20	20	Y60R	8	12	50	+12	+8	+10
4	20	40	Y30R	20	10	Y30R	6	18	82	+14	−8	+12
4	30	40	Y40R	20	10	G90Y	8	10	165	+12	0	+55
4	30	40	Y40R	20	10	B10G	5	9	300	+15	+1	+10
4	40	40	Y50R	35	2	Y	20	5	90	+15	−3	−10
4	40	40	Y50R	20	10	B10G	6	8	300	+14	+3	+10
4	40	40	Y60R	20	20	Y60R	8	15	91	+12	+5	+51
4	40	40	Y60R	20	10	G90Y	5	5	70	+15	+5	−40
4	40	50	Y70R	20	10	B10G	6	19	304	+14	−9	+14
4	40	50	Y70R	20	10	Y30R	10	17	113	+10	−7	+43
4	30	10	Y80R	20	10	G90Y	7	9	176	+13	+1	+66
4	30	10	Y80R	20	10	Y30R	5	5	80	+15	+5	+10
4	30	10	Y80R	30	10	Y10R	8	10	110	+23	0	+20
4	30	10	Y80R	20	10	B10G	9	9	235	+11	+1	−55
3	20	20	B90G	20	20	Y60R	10	20	17	+10	0	−23
3	20	20	B90G	10	10	Y20R	6	14	115	+4	−4	+35
3	5	15	G20Y	20	10	B10G	13	17	310	+7	−7	+20
3	5	15	G20Y	20	10	Y30R	17	15	80	+3	−5	+10
3	20	20	G30Y	10	10	Y20R	5	8	151	+5	+2	+71
3	20	20	G30Y	20	20	Y60R	5	20	60	+15	0	+20
3	20	20	G30Y	30	20	Y40R	23	17	23	+7	+3	−37
3	30	30	G90Y	20	20	Y60R	7	20	23	+13	0	−17
3	30	30	G90Y	30	20	Y40R	23	23	90	+7	−3	+30
3	20	60	Y10R	20	10	B10G	5	10	297	+15	0	+7
3	30	50	Y20R	20	10	G90Y	7	10	142	+13	0	+32
3	30	50	Y20R	20	10	Y30R	7	8	90	+13	+2	+20
3	30	50	Y20R	20	10	B10G	5	17	293	+15	−7	+3
3	30	50	Y20R	20	20	Y60R	7	23	43	+13	−3	+3
3	30	50	Y20R	30	20	Y40R	17	12	57	+13	+8	−3
3	20	40	Y30R	20	10	G90Y	9	7	162	+11	+3	+52
3	30	40	Y40R	20	10	Y30R	8	9	94	+12	+1	+24
3	30	40	Y40R	10	10	Y20R	5	5	62	+5	+5	−18
3	30	40	Y40R	30	10	Y10R	18	5	90	+12	+5	0
3	30	40	Y40R	20	20	Y60R	6	28	42	+14	−8	+2
3	40	40	Y50R	20	20	Y60R	10	14	36	+10	+6	−4
3	40	40	Y50R	20	10	Y30R	8	13	87	+12	−3	+17

(Continues)

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE A1 (Continued)

Global induction effect	Nominal background color in NCS			Nominal figure color in NCS			Induced figure color in NCS			Difference induced-nominal in NCS		
	S	C	H (Standard)	S	C	H (Standard)	S	C	H [0–400]	S	C	H [0–400]
3	40	40	Y50R	20	10	G90Y	13	7	145	+7	+3	+35
3	40	40	Y60R	30	20	Y40R	22	14	46	+8	+6	−14
3	40	40	Y60R	20	10	Y30R	9	9	88	+11	+1	+18
3	40	40	Y60R	35	2	Y	23	5	127	+12	−3	+27
3	40	50	Y70R	30	5	Y50R	23	8	80	+7	−3	+30
3	40	50	Y70R	10	10	Y20R	5	7	97	+5	+3	+17
3	30	10	Y80R	20	20	Y60R	5	23	43	+15	−3	+3
2	20	20	B90G	20	10	Y30R	7	8	70	+13	+2	0
2	5	15	G20Y	20	20	Y60R	14	20	47	+6	0	+7
2	5	15	G20Y	30	20	Y40R	30	20	43	0	0	−17
2	5	15	G20Y	20	10	G90Y	10	13	112	+10	−3	+2
2	30	30	G90Y	20	10	B10G	8	12	287	+12	−2	−3
2	20	60	Y10R	10	10	Y20R	14	10	85	+4	0	+5
2	20	60	Y10R	30	20	Y40R	27	10	60	+3	+10	0
2	30	50	Y20R	10	10	Y20R	5	10	129	+5	0	+49
2	20	40	Y30R	10	10	Y20R	5	6	78	+5	+4	−2
2	40	40	Y50R	30	20	Y40R	27	15	62	+3	+5	+2
2	40	40	Y60R	10	10	Y20R	9	18	82	+1	−8	+2
2	40	50	Y70R	20	20	Y60R	9	16	38	+11	+4	−2
2	40	50	Y70R	30	20	Y40R	24	16	58	+6	+4	−2
2	40	50	Y70R	20	10	G90Y	5	10	110	+15	0	0
2	30	10	Y80R	10	10	Y20R	5	10	109	+5	+0	+29
1	5	15	G20Y	30	10	Y10R	28	13	86	+2	−3	−4
1	5	15	G20Y	10	10	Y20R	6	10	77	+4	0	−2
1	30	30	G90Y	10	10	Y20R	5	10	84	+5	−0	+4
1	30	40	Y40R	30	20	Y40R	26	20	61	+4	0	+1
1	40	40	Y50R	10	10	Y20R	5	10	77	+5	0	−3
1	30	10	Y80R	30	20	Y40R	24	20	60	+6	0	0

Note: Notations in NCS for nominal background color, nominal and induced figure color, and for the difference between induced-nominal figure color. With indication of blackness (S), chromaticness (C), and Hue (H). Hue is indicated in standard NCS nomenclature and in percentage, being R = 0, Y = 100, G = 200, B = 300, R10B = 390, and so forth. Positive hue difference: anticlockwise, negative: clockwise. If hue difference H = 200, opponent colors; if H = 100, color in the adjacent quadrant.

15206378, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/col.22856 by Universitat Politecnica De Valencia, Wiley Online Library on [23/08/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License