Published Paper

Article · November 2019

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International Review of Civil Engineering (I.RE.C.E.), Vol. 9, N. 5
ISSN 2036 - 9913 September 2018

Color Spaces Representation and Its Role in the Architectural Design

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Abstract – *The aesthetics production is one of the most essential requirements of any architectural scheme. In addition, the chosen color scheme is the base of the architectural presentation, starting from the architectural design stage on the computer screens to the printing stage of posters and architectural drawings, and then implementing the stage as a schedule execution embodiment. Thus, this study has focused on the denominator of all these stages that are represented in the color systems, deducted from the basic colors (RGB), the color spaces, and its simulations. This can be represented in a mathematical form, then it can be embodied as a technical form in order to simplify the capability of the transform, the transport, and the basic treatment on it utilizing proper mathematical formulas for each color system or color space. Subsequently, directing the ideal methods in the printing process is led by an accurate simulation of the colors with the virtual existence. This paper includes the use of the color wheel and of the color grading, some simulations of the colors mixing processes, and the ratios changing method using MATLAB software. The study shows the reflection of the color assortment in the architectural design.* ***Copyright © 2018 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords*: Basic Colors, Color Spaces, Color Wheel, Architectural Presentation*

Nomenclature

CIE	International Commission on illumination
CMYK	Cyan, Magenta, Yellow, and key black
RGB	Red, Green and Blue
ICC	International Color Consortium
CMM	Color Management Module
X, Y, and Z	First color space axes
LUV, LAB	Color space
CIECAT02	Adaptive Space
CMM	Color Management Module
CMYKOG	Hexachrome six-color printing

I. Introduction

Light is a part of the spectrum of the electromagnetic radiation. The length of the optical wave is between 400 nm and 700 nm. The light is among the infrared and the ultraviolet light as shown in Fig. 1. It is the basic element of vision, which has a speed of 299,792 km/s. Color is the apparent state of body or the light portion that is described as arising entirely from the person's perception of the color characteristics. Such characteristics are represented by intensity or Chroma, which simply means the amount of color purity or the strength that is purer than the emptiness of any color mixing (Value) [1]. Color value, which is the amount of gradient from white to black, represents the value of color saturation with light or brightness and shadow or the value between pure color and other pure colors adjacent to Hue, which is a color label through which colors can be distinguished each other [2]. The light emitted from a chromatic source has a meaning that the light of a body is green or red; the coloration of the color has an explicit meaning, which is agreed upon by more than one person.

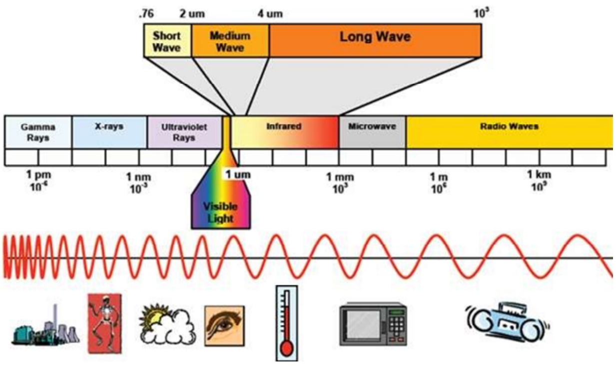


Fig. 1. Electromagnetic radiation and visible spectrum of the human eye

There is an additional classification of the color value depending on its correlation with white and black, which is the Tint. It refers to the classification of the color that consists of adding the white color to that color to make it smaller or bigger value than its original one. Shade is distinguished by adding black color to another color to turn it darker or less valuable than before. Tone is the addition of gray color (white+black) or the addition of complementary color in the direct circle of basic colors [3].

II. International Lighting Committee

The reason of establishing the International Lighting

https://doi.org/10.15866/irece.v9i5.14992

Committee is the great development of visuals along with the appearance of the twentieth century. It includes the emergence of colored cinema films, color photographs, car industry, color pigments, home dyes, beauty products, and hair dyes. In 1950, Koleston produced the first coloring screen in the world, and called for the establishment of a chromatic dye classification. The spread use of color printing of books, newspapers, magazines, etc. has been necessary to define a universal standard for colors. Thus, this committee was established in 1931 and was located in Vienna, Austria [5]. It was mandated to initiate light, lighting, and color space standards that has turned to be an international color diagram, as in Fig. 3. It had the name with the 1931 plan, relative to the year of issuing. This has become a custom for all subsequent editions of the International Lighting Committee that has been named in relation to the year of issue.

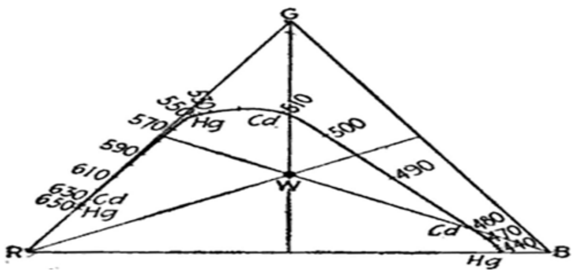


Fig. 2. The Maxwell's Triangle

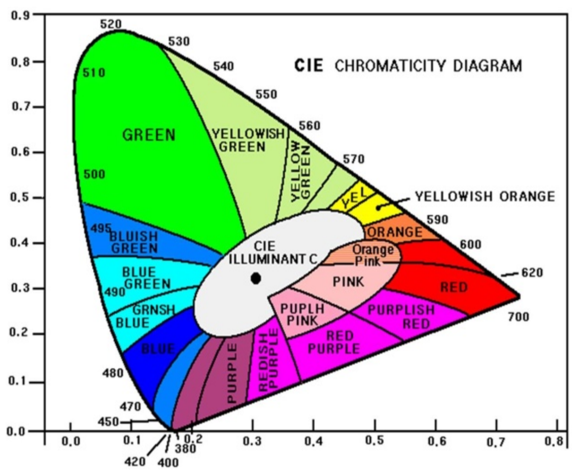


Fig. 3. The plan of the International Lighting Committee 1931 [5]

The organization has eight divisions, each one with a technical committee carrying out its program under the supervision of the department director: 1. Vision and color. 2. Light measurement and radiation 3. Design of Lighting and interior environment. 4. Lighting and transport signals. 5. External lighting and its applications. 6. Photovoltaic Biology 7. Photochemistry 8. Photo technology.

III. Color Space

The first color space (X, Y, and Z) was developed in 1931 at the International Lighting Association meeting at Cambridge University, and it was followed by the continuous development of the International Lighting Commission (CIE1960, CIE1976, and CIE2000). (LUV, LAB) and Adaptive Space (CIECAT02) also developed, where the system is centered on three intermediate axes (Medium, Short, and Long) and the color space (CMYK), which is used in printing [6].

III.1. Color Spaces for Printers and Color Coordination

CMYK is used in printing because it is not possible to use the RGB color space. Its center is the white color, which is the same color as the white papers. As a result, we lose the key feature in the color mixing process is lost. The CMYK color space is centered in black, which is opposite to the paper color used in printing. The printer has four colors: Cyan - Pink (Red - Purple) - Yellow – Black, so that the color presentation is suitable for printing, as seen in Fig. 4; the differences between the two parts can be summarized as follows:

- RGB is created because of the overlapping of the three main colors: Red - Green - Blue [7].
- CMYK is created because of the overlapping of the four main colors: Celestial (C), Magenta (M), Yellow (Y), and Black (K) [8].
- RGB is known as the Additive Colors; the output of the three main color overlays gives the color white.
- CMYK is known as the Subtractive Colors; its main color overlap produces black.

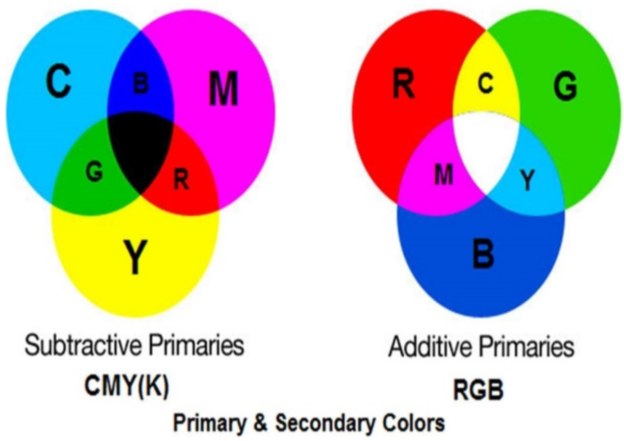


Fig. 4. Difference between RGB and CMYK [8]

III.2. Mathematical Representation of the CMYK Chromatography Process

The CMYK color scheme partially or completely eliminates certain colors on a white background by absorbing some wavelengths of light. This model is described as a subtractive model because inks produce some brightness of white [8]. In complex color schemes, such as RGB, white color is the sum of all primary colored lights, while black is the absence of light. CMYK color scheme is reversed, where white is the natural color of the paper or printed surface, and black is a result of overlapping colored inks on top of each other. In order to save expenses in the inks, and in order to obtain the black color, black ink is used instead of overlapping cyan, magenta, and yellow.

III.2.1. Converting RGB to CMYK

For the purpose of conversion, the three primary color values of RGB are divided by 255 in order to obtain the percentages of these colors between zero and 1 as follows [9]:

$$R' = \frac{R}{225},\ G' = \frac{G}{225},\ B' = \frac{B}{225}$$

From these values, the value of the colors can be calculated from the following equations:

$$K = 1 - \max(R', G', B') \quad (1)$$

$$C = (1 - R' - K)/(1 - K) \quad (2)$$

$$M = (1 - G' - K)/(1 - K) \quad (3)$$

$$Y = (1 - B' - K)/(1 - K) \quad (4)$$

The results of the conversion as shown in Table I.

III.2.2. The Reverse Conversion from CMYK Color System to RGB Color System

The reverse conversion results are obtained from the values of the original RGB system (0 - 255) of the CMYK system, as in the following equations:

$$R = 255(1 - C)(1 - K) \quad (5)$$

$$G = 255(1 - M)(1 - K) \quad (6)$$

$$B = 255(1 - Y)(1 - k) \quad (7)$$

Therefore, the reverse conversion results are shown in Table II.

IV. The Problem of Architectural Presentation

During the attempt to perform an architectural design on the computer screen using RGB, printing it, and converting it to CMYK system, there is a change in color, which may affect the beauty of the design. The same situation happens when dragging a paper image from the scanner to the computer. The colors are not exactly as the same degree as of the colors of the original image, because each device produces a change to some degree in colors.

TABLE I
THE RESULTS OF CONVERSION FROM RGB TO CMYK

Color	Color name	(R,G,B)	(C,M,Y,K)
	Black	(0,0,0)	(0,0,0,1)
	White	(255,255,255)	(0,0,0,0)
	Red	(255,0,0)	(0,1,1,0)
	Green	(0,255,0)	(1,0,1,0)
	Blue	(0,0,255)	(1,1,0,0)
	Yellow	(255,255,0)	(0,0,1,0)
	Cyan	(0,255,255)	(1,0,0,0)
	Magenta	(255,0,255)	(0,1,0,0)

TABLE II
REVERSE CONVERSION RESULTS FOR RGB AND CMYK SYSTEM [8]

Color	Color name	(C,M,Y,K)	(R,G,B)
	Black	(0,0,0,1)	(0,0,0)
	White	(0,0,0,0)	(255,255,255)
	Red	(0,1,1,0)	(255,0,0)
	Green	(1,0,1,0)	(0,255,0)
	Blue	(1,1,0,0)	(0,0,255)
	Yellow	(0,0,1,0)	(255,255,0)
	Cyan	(1,0,0,0)	(0,255,255)
	Magenta	(0,1,0,0)	(255,0,255)

Thus, the color organization makes the files appear constant in all the device, such as the screen, the scanner, and the printer. Another problem of colors in architectural works is the difference between the true colors of the existing buildings in CMYK color scheme, such as the historic buildings and the modern ones. The same problem occurs to the colors of images taken by camera, represented on screens, as GBR color screen, to perform any architectural development, rehabilitation, or conservation treatments. This is usually done on the computers' screens according to the colors obtained from the original buildings.

The difference of colors between the existing buildings and their images on screens is a serious problem for the architects and the designers, whether for exterior facades or the interior designs. The problem is extended for the different building materials and finishes. Despite all attempts by the production companies in designing strong color organizing systems through programs to help the stability of color files, the problem has not completely solved. Within the differences that can be easily observed there is the one between the colors on the screen with its represented similar ones done by mixed ink on posters and papers, which do not produce the same quite grades.

The components sharing the presentation of the apparent colors on the screen are more than the others produced by the inks, because these two generic colors differ in color space. The special system of color space RGB system is larger and wider than the color space of the CMYK system [8].

IV.1. The Colors in the Architectural Presentation

The process of color organizing in the architectural presentation depends on the color wheel (Fig. 5), which has no relationship with the order and the context of the color systems and technical color spaces.

Fig. 5. The color wheel

Most of the color wheels depend on three main colors, three secondary colors, and six intermediate colors, which were consisted by mixing a main color with a secondary color, named tricolors. They form a total number of 12 basic sections. There is also a color wheel consisted of 24 sections [9].

IV.1.1. Psychological Effects of Color Characteristics

The strong colors of high intensity are naturally exciting; they may tire the eye. It is preferable to use them in places of movement such as markets.

Meanwhile, the colors of medium intensity helps in social interaction. The low intensity colors may hide the color to become pale. In other words, the high value of the color is exciting, the medium value gives a sense of comfort, and the low value gives a feeling of pain and boredom. The colors and their significances are expressed philosophically and they vary from person to person, having no scientific reference. Consequently, colors and their indications can be summarized as follows:

- Red: It is associated with emotion, passion, enthusiasm, courage, blood, and life force, because it gives the impulse and the sensation of excitement.
- Blue: It is associated with sincerity, hope, serenity, and reservation, because it is cool and it gives a sense of calm and reverence, but using it in high intensity leads to a feeling of depression.
- Yellow: It represents the sun and the religious splendor, and it is the warmest color associated with joy and humor. It gives the basis of supervision and a less sense of tension compared to red and orange.
- Green: It is associated with religion, immortality, spiritual meditation, and the clothing of the people of Paradise. It expresses sweetness and purity in the normal use, and most theories tend to use it in the office and studying space, because it gives stability and comfort.
- Violet: It is carefully associated with remorse and repentance; it is a pleasant and a gentle color and is preferably used.
- Neutral colors: They have the ability to create mood and mental connections; white is associated with honesty, purity, and innocence, because it represents clarity and openness, gray is the combination between white and black, and it indicates reverence, modesty, and humility. Finally, the black color is a sign of sadness and it is associated with pessimism, horror, and secrecy [9].

IV.2. Problem Solving of the Architectural Presentation

In order to find solutions to the problem of the architectural presentation, also, in order to fill the gap between the colors on the electronic devices, such as screens, monitors, data shows, RGB systems, colors appearing in printing posters machines, drawing sheets, papers, SMYK systems, and for any architectural works (by getting back to the theoretical background of the research), the following points can be summarized:

1. The International Color Consortium (ICC) has reduced the problem of variance in colors between architectural design presentation and the printout images by creating electronic equipment and software to create a transition phase called a Color Management Module (CMM) [10].
2. Increasing the color space by creating RGB system for designers who rely on image conversion to CMYK when printing to minimize the effect of the difference.
3. When printing, CMYK system must be used, instead of RGB system to determine the resulting image, because the risk of printing on RGB system doesn't give a pre-knowledge of the result in advance; it is better to start with CMYK system without a need for this conversion.
4. The conversion from RGB system to CMYK must not exceed one time, because this will lose much of the original design. Therefore, if necessary, it must be done once only.
5. It is possible to switch to an intermediate system, which is close to the two systems. It is suitable to utilize the LAB system, rather than the direct conversion from RGB system to CMYK system, then to the other system [11].
6. Avoiding using the green color too much in architectural designs, because the green's color area in CMYK system is very weak. If it is very necessary to use the green color heavily in the architectural works, it is preferable to start from the beginning with CMYK system.
7. Expanding the number of inks in printers to include six colors instead of four colors, as in printers of CMYKOG type.
8. Making use of the printer's quality menu, where there are nine types of color modelling sets [12].
9. Noticing the following points to reduce the problems of the architectural presentations, and taking in consideration the practical experience:
   - Improving the color convergence between screen and printer outputs [12].
   - Dealing with papers and sheets according to its nature and the way it absorbs ink, and giving attention to their qualities, which are not standardized in texture or color. This may require

different kinds of inks [13].
- Using of large, high-resolution, and high quality printers.
- Using of high quality inks with high specifications.
- Using of mineral inks and varnishes, which enhance the glossy appearance of the printed piece [14].

V. Practical Part Using MATLAB Software

The practical side includes the development of a simulation model using MATLAB. It is for the virtual reality of the process of converting colors from the main color space, used in RGB system, to the color space used in CMYK system by color printers. The special values of the elements of each system have been changed carefully to see the behavior of the grayscale output. Fig. 6 shows that the values of all colors are of a value equal to zero (0), and that the value of the black color (k) determines the gray color.

	cmyk(0%, 0%, 0%, 4%)		cmyk(0%, 0%, 0%, 14%)	
	cmyk(0%, 0%, 0%, 17%)		cmyk(0%, 0%, 0%, 25%)	
	cmyk(0%, 0%, 0%, 34%)		cmyk(0%, 0%, 0%, 50%)	
	cmyk(0%, 0%, 0%, 59%)		cmyk(0%, 0%, 0%, 59%)	
	cmyk(0%, 0%, 6%, 0%)		cmyk(0%, 0%, 10%, 4%)	

Fig. 6. The grayscale of CMYK system

In order to spot the light on the special outputs of the colors individually, some colors have been chosen as in Fig. 7.

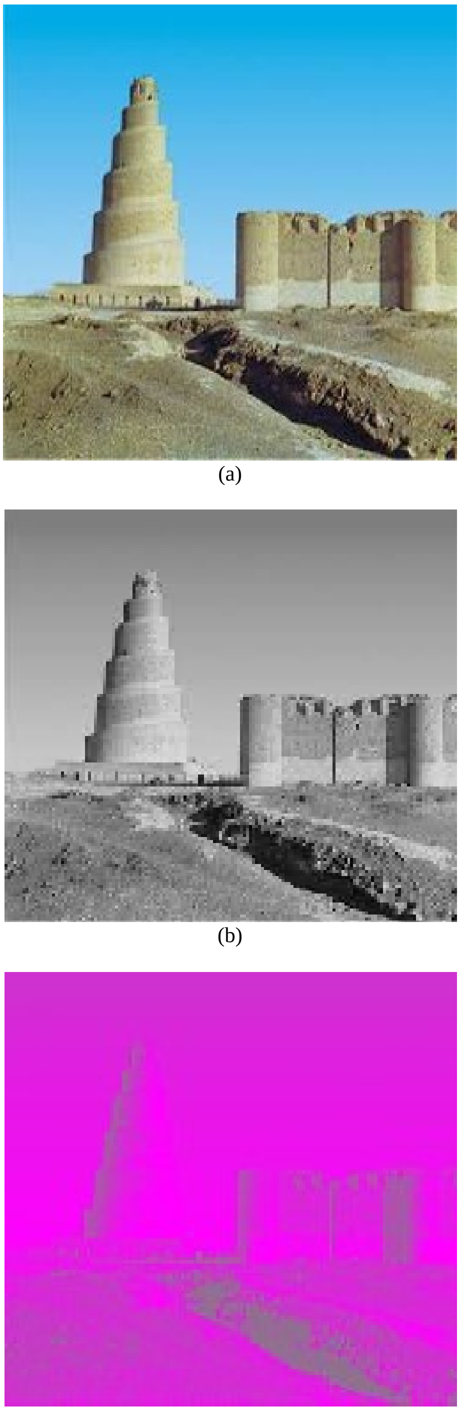
yellow	(C=0%, M=0%, Y=100%, k=0%)
Yellowish green	(0%, 0%, 100%, 50%)
Orange	(0%, 46%, 93%, 7%)
Pink	(0%, 100%, 0%, 0%)
Red	(0%, 100%, 100%, 0%)
Green	(100%, 0%, 100%, 0%)

Fig. 7. Special outputs of some colors in CMYK system

Therefore, it is noted that all the ratios of the main colors (C, M, Y and K) change according to the nature and the degree of the secondary or the triad color. In addition, the main color preserves a constant ratio, which is 100%.

The other side of the practical application selects a test image (Samarra Spiral Minaret). One of the distinctive landmarks of Iraq. Because of its unique form, it is one of the most famous art pieces of archaeological heritage of ancient Iraq.

Originally, it was built as a minaret of the great mosque of Samarra City, founded by the Abbasid Caliphate, Al-Mutawakil, in 237 AH. The nature of the colors of the test image are in Figs. 8 [15].



(a) (b) (c)

Figs. 8. (a) The image of Samara Minaret in RGB (b) Add black by 50% (c) Black 50% and Pink 50%

VI. Discussion

Color is a phenomenon, not a natural dimension such as length or temperature. It is the gentle electromagnetic beam of the visible wavelength, which is measurable as a natural quantity.

Thus, there is an appropriate form of representation of the mathematical requirements algorithm for the purposes of image processing, camera technology, printer, visual data show, and nature of color sense of the human being. These different requirements cannot be together. For this reason, the usable representation varies according to the purpose of processing in the application used. For printing purposes, inks or inks powders of cyan, magenta, yellow, and black colors are used according to CMYK system in different quantity ratios to produce a large range of colors in nature.

Practical programs specify colors of images or architectural drawings converting RGB and CMYK systems. Usually, the color conversion tables used in Auto Color Correction typically match the standard screen colors of the calculator with the output of different devices.

Many colors are affected by screen differences and lighting conditions due to technical differences between Printers and screens, as well as the environmental conditions, paper type, lighting conditions, and user preferences. This problem shows a clear difference between the architectural design outputs on the computer screen and the output on paper. The customer or the beneficiary of the architectural design sees what is presented on paper, which usually differs from that on the computer screen. Consequently, in order to remedy this situation, the aforementioned steps and solutions should be followed, as shown in this paper in section IV.2.

Companies of computers, screens, printers, plotters, and other concerned devices continue to improve their performance through the production of high-quality printers, as well as improved operational and application programs of color systems. The skill of architects and workers is the most important thing in improving performance through the constant observation of performance and accumulation of practical experience of work.

VII. Conclusion

RGB system uses three colors (Red - Green - Blue) as the main colors in the formation of all other colors by mixing these t in different proportions. Furthermore, CMYK system uses four colors (Cyan-Magenta-Yellow-Black) in order to obtain the remaining colors. Such a system is specialized in printing works, because the printers working in this field print the colors with four heads.

There are usually some damages in colors, which are resulting from the change of color systems. Such damages lead to a difference in purity of colors between the basic architectural design on the computer screen and its colors on paper after printing. Therefore, scientific steps must be taken. Some of which are implemented by multiple assistive programs to reduce color differences by taking additional operational actions, including the selection of suitable papers, the use of high quality printers, and the use of accumulated field experience as described above.

VIII. Future Recommendations

There must be a coordination with the different manufacturers to improve the color systems, the quality of inks, and the practical programs involved in converting the color systems. This is for producing high quality printers and plotters that reduce the difference between the colors of the basic architectural design and the output of the printer. In addition, these steps must insure avoiding the wide variation between the virtual colors appearing on the electronic displays of the computers used in the architectural design and the realistic colors on the printed posters, the architectural images, and the detailed drawings, which are adopted in the implementation of the design.

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