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A Comparison of Extracted Dominant Colours of Twelve Cosmopolitan Cities

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Abstract: ***Metropolitan cities are large multi-cultural urban areas. Their colour schemes, which contribute to their unique identities, are influenced by factors, such as when the city was established, climate, city ordinances, and cultural heritage. City colours also evolve overtime due to new construction materials, innovative building designs, and urban development. The objective of this study is to determine if there are similarities in dominant colours for twelve metropolitan cities spanning six continents. They include Cairo, Cape Town, Singapore, Tokyo, Perth, Sydney, London, Madrid, Mexico City, New York City, Buenos Aires, and Lima. The Fuzzy C-Means (FCM) colour extraction technique was used to extract five dominant colours from images of these twelve cities. The extracted dominant colours were outputted as hexadecimal codes with their corresponding names obtained from the color-name.com website. Results show that some of these cities have similar dominant colours. Two colours, cobalt blue and sonic silver, are found in 25% of the cities. Furthermore, ten colours are present in pairs of cities. Most notably, some cities share two of the five dominant colours. Mexico City and New York City both have eerie black and platinum in their colour schemes, while Singapore and Lima share Charleston Green and Gainsboro. Cape Town and Perth both have light cobalt blue and sonic silver in their colour patterns, while Madrid and Buenos Aires share khaki and shadow colours. Dominant colours identified as a result of this investigation could be used to produce colour palettes for these cities. Since colour is an important component of urban development and preservation projects, the ones that incorporate aspects of existing colours would create buildings that are harmonious with the cultural heritage as well as the overall colour scheme of this city.***

Keywords: Colour extraction, Fuzzy c-means (FCM), soft clustering, unsupervised learning, machine learning, cosmopolitan cities, dominant colours, city colour palettes

I. INTRODUCTION

Cosmopolitan cities are densely populated urban areas inhabited by people from many cultures [1]. They may be ancient or modern. Cities, such as Cairo and Mexico City are ancient cities as they have been in existence for countless millennia [2-3]. Singapore and Perth, by contrast, are modern cosmopolitan cities [4-5]. Colours contribute to the character of cities, and they are impacted by several factors. They include when these cities were established, climate, city ordinances, and cultural heritage. When an ancient city was first founded, most of the construction supplies were locally sourced; thereby limiting the number of colours used in urban design [6]. Many ancient Egyptian buildings, for example, were constructed from locally quarried stones and from bricks made from Nile River mud [7]. Modern cities tend to have colours that include various shades of grey due to construction materials for high-rises and the compatibility of grey with many other colours [6,8]. Climate also impacts a city's colour scheme. Las Palmas (Canary Islands) is generally warm and humid in the summer [9]. Because of this reason, houses have colourful roofs to decrease heat load of these buildings [10]. City colours are also affected by city ordinances. When Albert Kikkert was governor of Curaçao (Lesser Antilles), he believed that whitewashed buildings reflected so much sunlight that it caused excessive glare resulting in eye strain. Hence, he required all buildings to be painted in any colour other than white [11]. Cultural heritage also affects city colours. During the Spanish colonial era, buildings in Izamal (Mexico) were painted yellow in honour of the Mayan culture. According to their belief system, Izamal was the home of their sun god, Kinichkakmo [12].

City colours could be identified by using colour extraction methods. These are machine learning techniques that obtain dominant colours from images. [13-15]. Colour extraction techniques divide pixels into groups of similar colours that are known as clusters [15]. Each group of pixels is defined by a centroid, which is one of the dominant colours [14]. Colour extraction algorithms are also divided into hard and soft clustering methods [16]. Hard clustering methods, such as K-Means clustering, assign each pixel to only one cluster, while soft clustering techniques, such as Fuzzy C-Means (FCM), assign pixels to multiple clusters [17].

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This investigation compares the extracted dominant colours for twelve cities that are spread across six continents. They are Cairo, Cape Town, Singapore, Tokyo, Perth, Sydney, London, Madrid, Mexico City, New York City, Buenos Aires, and Lima. This study involved downloading publicly available pictures of these cities from the web. FCM clustering with five clusters was applied to these images so that five dominant colours could be extracted from the photographs for each city. These colours were outputted as pie charts showing the hexadecimal codes that were then inputted to the color-name.com website to obtain their colour names [18]. Extracted dominant colours could be used to create colour palettes for each of these cities. The inclusion of existing colours in construction projects ensures that new designs are compatible with the existing urban fabric. Furthermore, the colour extraction procedure used for this investigation could be applied to other environments to develop colour palettes for these locations.

The remainder of this paper is structured as follows: Section 2 provides a brief description of the cites that were used to perform the colour extraction studies. Section 3 describes the Fuzzy C-Means (FCM) colour extraction technique. Section 4 provides an overview of the experimental procedure, while section 5 reviews the experimental findings for this investigation. Section 6 concludes this study and briefly discusses follow-on experiments.

II. BRIEF DISCUSSION OF COSMOPOLITAN CITIES

Images of twelve cosmopolitan cites located in six continents were utilized to extract dominant colours for this investigation. Table I provides information for these locations.

TABLE I
INFORMATION ON WORLD CITIES

Continent	City	Latitude/Longitude	Population
Africa	Cairo	30.033333, 31.233334 [19]	21,750,020 [20]
	Cape Town	-33.918861, 18.423300 [21]	4,800,954 [22]
Asia	Singapore	1.290270, 103.851959 [23]	6,039,577 [24]
	Tokyo	35.652832, 139.839478 [25]	37,274,000 [26]
Australia	Perth	-31.953512, 115.857048 [27]	2,092,649 [28]
	Sydney	-33.865143, 151.209900 [29]	5,056,571 [30]
Europe	London	51.509865, -0.118092 [31]	9,540,576 [32]
	Madrid	40.416775, -3.703790 [33]	6,713,557 [34]
North America	Mexico City	19.432608, -99.133209 [35]	22,085,140 [36]
	New York	40.730610, -73.935242 [37]	8,177,025 [38]
South America	Buenos Aires	-34.603722, -58.381592 [39]	15,369,919 [40]
	Lima	-12.046374, -77.042793 [41]	11,044,607 [42]

Cairo, located along the Nile River, is the capital of Egypt. It is sited near its ancient capital that was established in 3100 BCE [2]. This city's architecture is influenced by its rich heritage. The eastern parts of Cairo were developed over many centuries, while the western areas were based on the layout of Paris with open green spaces and tree-lined streets [2]. The two images of Cairo that were used for colour extraction are shown in Fig. 1.



Fig. 1 Images of Cairo [43-44]

Cape Town, established in 1652, is the legislative capital of the Republic of South Africa. Portions of this city were built along the slopes of Table Mountain, while other portions extended to the flat areas that are located adjacent to bays [45]. The two images that were used to extract dominant colours are provided in Fig. 2.



Fig. 2 Images of Cape Town [46-47]

Singapore, a city-state, is situated off the Malay Peninsula [48]. It was established by the Sumatran Srivijaya kingdom (present-day Indonesia). It later became a British colony, for 140 years, until it gained independence in 1965 [4]. Singapore is also known as a "City in a Garden" due the abundance of green space despite being a major cosmopolitan city [48]. Images that were used for colour extraction are provided in Fig. 3.



Fig. 3 Images of Singapore [49-50]

Tokyo, located along Tokyo Bay on Honshu, is the capital of Japan [51]. It was established as a fishing village about 3,000 BCE [52]. As this city grew, residential neighbourhoods sprang-up between commercial centres [51]. The types of buildings found in Tokyo range from contemporary high-rise buildings to Minkas that are houses with sliding doors and Tatami flooring [53]. Images that were used for colour extraction are provided in Fig. 4.



Fig. 4 Images of Tokyo [54-55]

Perth, sited in western Australia, is situated along the shores of the Swan River. It is a major industrial centre [5]. Perth images that were used for colour extraction are shown in Fig. 5.

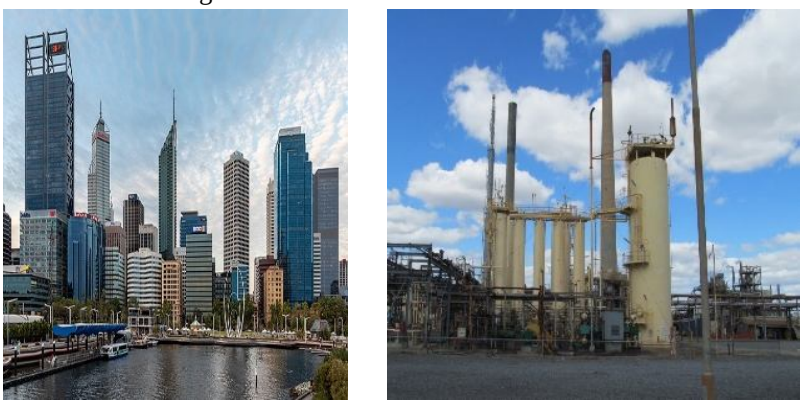


Fig. 5 Images of Perth [56-57]

Sydney, located in the south eastern Australia, is this continent's most densely populated city. It borders Sydney Harbor; as such, it has many inlets and bays. This city has a compacted central commercial area with low-density residential areas radiating from it due to the appeal of home ownership to many Australians [58]. Photographs that were used to extract dominant colours are shown in Fig. 6.



Fig. 6 Images of Sydney [59-60]

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London, located in southeast England, is the capital of the United Kingdom [61]. It was first settled about 6,000 BCE, but it was established in 43 CE by the Romans [62]. This city was developed from three separate areas that were subsequently interlinked over the centuries; as such, it is a polycentric city. Because of this reason, its building styles range from modern skyscrapers to designs of bygone eras [61]. Pictures that were used for colour extraction are provided in Fig. 7.



Fig. 7 Images of London [63-64]

Madrid, located at the centre of the Iberian Peninsula, is the capital of Spain [65]. It was first recorded in 865 CE [66]. Madrid's buildings reflect many architectural styles ranging from skyscrapers, neoclassical buildings that flourished around the 1750s, and medieval town squares [65]. Neighbourhoods, known as barrios, have their unique flair. They are divided into upper, middle, and lower quarters [65]. Images of Madrid used for colour extraction are provided in Fig. 8.



Fig. 8 Images of Madrid [67-68]

Mexico City is the capital of Mexico [69]. It has been settled for more than 7,000 years, and it was established as Tenochtitlán, in 1325 CE [3, 70]. This city is one of the densest and continuously populated cites in the Western Hemisphere. Its building styles range from modern high-rises, mansions with steep roofs, barrios that resemble rustic villages, and historic buildings to include the Aztec Templo Mayor [71]. Pictures that were used to extract dominant colours are provided in Fig. 9.



Fig. 9 Images of Mexico City [72-73]

New York City, located in the southeast part of New York State, is the most densely populated city in the United States of America [74]. This city, established in 1624, is made up of five boroughs to include Brooklyn, Bronx, Manhattan, Queens, and Staten Island [75]. Its building styles range from skyscrapers, apartment buildings, townhouses, and single-family houses. Many high-rises are found in Manhattan [76]. Pictures that were used for colour extraction are provided in Fig. 10.



Fig. 10 Images of New York City [77-78]

Buenos Aires, the capital of Argentina, was founded in 1536. Its city centre is located at Plaza de Mayo [79]. When Buenos Aires was re-developed in the early twentieth century, it was based on the design of Paris [80]. Because of this reason, it has tree-lined streets with green spaces [79]. This city has distinctive barrios with their unique styles, and these buildings have the characteristics of Latin American architecture [79]. Photographs that were used for colour extraction are provided in Fig. 11.



Fig. 11 Images of Buenos Aires [81-82]

Lima, located in the Chillón, Rímac, and Lurín River valleys, is the capital of Peru [83]. It was founded in 1535 [83]. Although Lima has many modern skyscrapers, its architecture is influenced by its Incan and Viceroyal heritages with some of its buildings listed as UNESCO World Heritage sites [84]. Pictures that were used for colour extraction are provided in Fig. 12.



Fig. 12 Images of Lima [85-86]

III.DISCUSSION OF FUZZY C-MEANS CLUSTERING

Fuzzy C-Means (FCM) clustering is a colour extraction technique. It sorts pixels into groups of similar colours that are specified by a centroid, which is one of the dominant colours for a Red Green Blue (RGB) image [87]. The set of pixels, *X*, and the set of centroids, *V*, for an image are specified as follows

$$X = \{x_1, x_2, \dots, x_n\} \quad (1)$$

$$V = \{v_1, v_2, \dots, v_c\} \quad (2)$$

where X is the set of all pixels, $\boldsymbol{x}_1$ is the first pixel, n is the total number of pixels, V is the set of all centroids, $\boldsymbol{v}_1$ is the first centroid, and c is the number of centroids [87-89]. For a RGB image, the colour for each pixel and centroid is specified by a red, a green, and a blue coordinate.

The FCM technique is a soft clustering method because pixels have a degree of membership for every cluster. The membership degree, u_{ij}, specifies the probability that pixel, j, belongs to cluster, i, and the u_{ij} values for a pixel add up to one. In addition, the membership matrix, $\boldsymbol{U}$, consists of all the membership degrees, u_{ij}.

The first step for this clustering method is to initialize the input variables that are set by the programmer. They include the fuzzifier factor, m, the maximum number of iterations r, the number of clusters, c, and the threshold, β [90]. The membership degrees in the membership matrix are initialized with random probabilities, under the restriction that each pixel's membership degrees sum to one. Each centroid is initialized with a random RGB colour. This technique then iteratively calculates the centroids and the membership degrees as follows:

$$\boldsymbol{v}_i = \frac{\sum_{j=1}^{n} u_{ij}{}^{m} x_j}{\sum_{j=1}^{n} u_{ij}{}^{m}} \tag{3}$$

$$u_{ij} = \frac{1}{\sum_{k=1}^{c} (D_{ij}/D_{kj})^{2/(m-1)}} \tag{4}$$

where m is the fuzzifier factor, $\boldsymbol{v}_i$ is the i^{th} cluster, $\boldsymbol{x}_j$ is the j^{th} pixel, and u_{ij} is the membership degree that relates cluster i to pixel j. In addition, k is a counter, D_{ij} is the distance between cluster i and pixel j, and D_{kj} is the distance between cluster k and pixel j [88]. This technique then calculates the termination criterion value as follows

$$\Delta = \left\| \boldsymbol{U}^{(t)} - \boldsymbol{U}^{(t-1)} \right\| \tag{5}$$

where Δ is the termination criterion value, t is the current iteration number, $\boldsymbol{U}^{(t)}$ is the current membership matrix, and $\mathbf{U}^{(t-1)}$ is the previous membership matrix.

The next step is to compare the termination criterion value, Δ, with the threshold value, β. If Δ is greater than β, the FCM method continues to iterate until the termination criterion value is less than the threshold vale [91]. The algorithm then terminates, and the final centroid colours are used as the dominant colours. Fig. 13 is the activity diagram for FCM colour extraction.

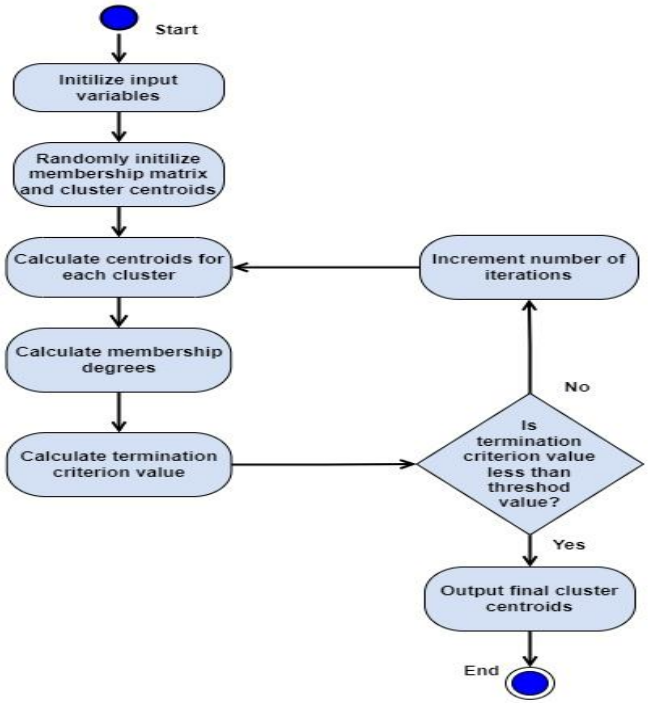


Fig. 13 Activity Diagram for FCM Colour Extraction

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IV. EXPERIMENTAL PROCEDURE

Since this investigation involved determining dominant colours of 12 metropolitan cities, the first step was to obtain two pictures for each of these cities. Publicly available images of these locations were downloaded using the Flickr, Pexels, Pixabay, Max Pixel, Rawpixel, Unsplash, and Wikimedia Commons websites [92-98]. A Python program, using the Fuzzy-c-means, Matplotlib, Numpy, and Pillow libraries, was then written to perform colour extraction for each of these cities [90, 99-101]. This program loads the two images for a city from their image files. These images are resized to 1080x1080-pixels, which is the standard image size [102-104]. FCM clustering is then applied to extract dominant colours from both pictures. The input parameters for the FCM clustering algorithm are a fuzzifier factor of two, a threshold of 10^{-5}, a maximum number of iterations of 200, and five clusters. This program performed five cluster extractions since colour palettes of cities typically have five colours [105-108]. The list of dominant colours for both pictures are combined so that FCM clustering can be performed on this combined colour list. This program then outputs the five most dominant colours for a location. The results are displayed as a pie chart showing the hexadecimal colour codes, which were inputted to the color-name.com website to obtain the colour names [18]. The general workflow for the colour extraction program is provided in Fig. 14.

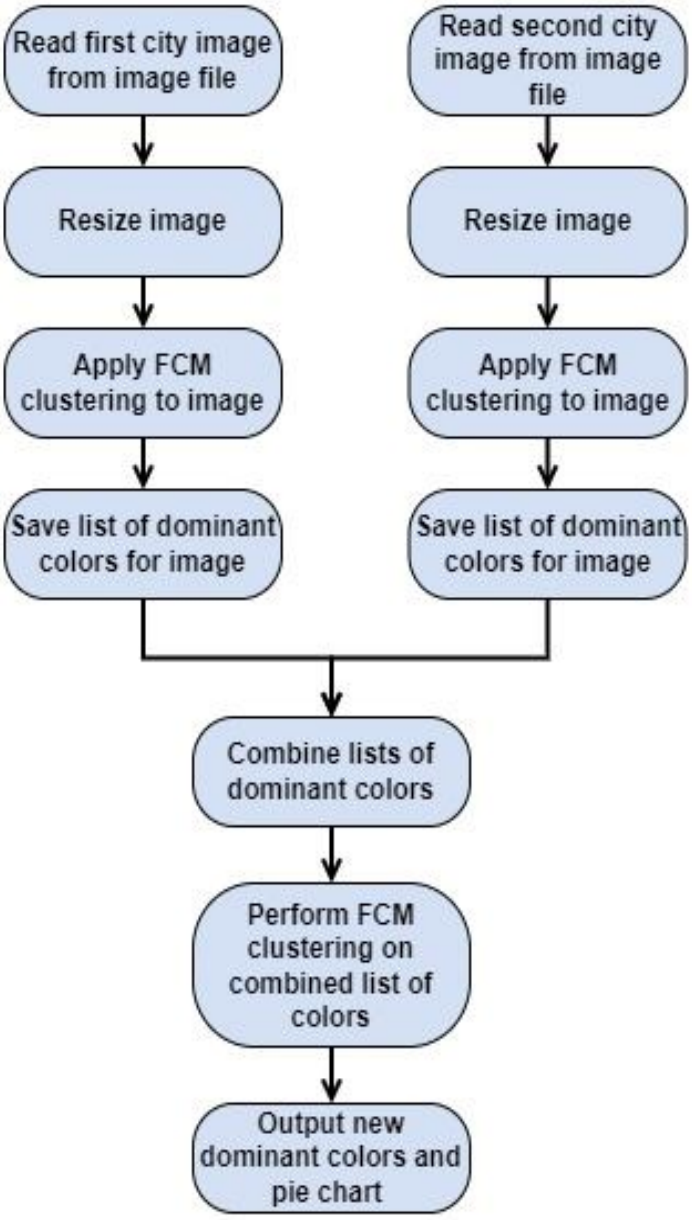


Fig. 14 General Workflow for Colour Extraction Program

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V. DISCUSSION OF RESULTS

Colour extraction using the FCM clustering method with five clusters was performed on the photographs of the twelve cities. The results were outputted as pie charts showing the hexadecimal codes of the dominant colours. The colour names corresponding to these codes were obtained by using the color-name.com website [18]. The results are summarized in Table II.

TABLE III
COLOUR EXTRACTION RESULTS TABLE

Continent	City	5 Colour Extraction	
		Hex Codes	Colours
Africa	Cairo	948971	Cinereous
		2a2418	Raisin Black
		5f5038	Olive Drab Camouflage
		d6c0ac	Dark Vanilla
		52b9d3	Sea Serpent
	Cape Town	757674	Sonic Silver
		3b3d36	Black Olive
		c5cdd1	Chinese Silver
		86aed9	Light Cobalt Blue
		0b83e4	Blue Cola
Asia	Singapore	7e8d96	Roman Silver
		52606a	Black Coral
		262d2c	Charleston Green
		d5dee4	Gainsboro
		8bb3d8	Light Cobalt Blue
	Tokyo	6b6c6e	Dim Grey
		46474b	Outer Space
		939394	Spanish Grey
		bdbdbb	Grey (X11)
		1d1f23	Dark Jungle Green
Australia	Perth	323537	Jet
		787871	Sonic Silver
		cfd8e0	Columbia Blue
		86b2db	Light Cobalt Blue
		467bc5	Cyan-Blue Azure
	Sydney	a4c3db	Pale Cerulean
		727779	Sonic Silver
		24303d	Gunmetal
		727e95	Slate Grey
		145174	Dark Cerulean
Europe	London	22201d	Raisin Black
		62615a	Granite Grey
		8e9391	Philippine Grey
		a7b7b8	Cadet Blue (Crayola)
		bfd2e8	Beau Blue
	Madrid	403327	Jacko Bean
		8e796b	Shadow
		e4d6c6	Bone
		bca797	Khaki (HTML/CSS)
		5a93ed	United Nations Blue

North America	Mexico City	5b4840 9f7965 bca89e 201a18 e6e3e1	Olive Drab Camouflage Blast-Off Bronze Tuscany Eerie Black Platinum
	New York City	e0dde5 484549 a59fa4 1c1b20 746f71	Platinum Outer Space Quick Silver Eerie Black Dark Silver
South America	Buenos Aires	c8b39f 191513 86786d 4b433d ebeef0	Khaki (HTML/CSS) Black Chocolate Shadow Dark Puce Bright Grey
	Lima	5b5555 a2a1a6 847874 2c2c2d dcdad8	Davy's Grey Quick Silver Grey (HTML/CSS Grey) Charleston Green Gainsboro

For Cairo, the colours are shades of brown, a shade of black, and a shade of blue. They are cinereous, raisin black, olive drab camouflage, dark vanilla, and sea serpent. The brown and black shades are due to the colour of the buildings. The colours for Cape Town are shades of grey with two shades of blue. They are sonic silver, black olive, Chinese silver, light cobalt blue, and blue cola. The shades of blue are due to the water and sky. For Singapore, the dominant colours are shades of grey and one shade of blue. These colours include Roman silver, black coral, Charleston green, Gainsboro, and light cobalt blue. These shades of grey reflect the colours of the skyscrapers, while the blue colour is caused by the water and the sky. For Tokyo, the dominant colours are shades of grey. These include dim grey, outer space, Spanish grey, grey (X11), and dark jungle green. These colours are the result of the numerous skyscrapers and roads in this city. The prominent colours for Perth are two shades of grey and three types of blue. These colours include jet, sonic silver, Columbia blue, light cobalt blue, and cyan-blue azure. The grey colours are due to the buildings, while the blue colours are due to the water and the sky. For Sydney, the dominant colours are shades of blue and grey. They consist of pale cerulean, sonic silver, gunmetal, slate grey, and dark cerulean. The blue shades are due to the colour of the harbour and the sky, while the greys are due to the skyscrapers. For London, the colours are two shades of grey, two shades of blue, and black. They include raisin black, granite grey, Philippine grey, cadet blue (Crayola), and beau blue. The shades of grey and black are caused by the roads, the buildings, and their shadows. The dominant colours for Madrid are four shades of brown and one shade of blue. These colours include Jacko bean, shadow, bone, khaki (HTML/CSS), and United Nations blue. The brown shades are due to the colour of the buildings. For Mexico City, the prominent colours are three shades of brown, a shade of black, and a shade of grey. These colours are olive drab camouflage, blast-off bronze, Tuscany, eerie black, and platinum. These shades are due to the numerous buildings and roads found in this city. The dominant colours for New York City include shades of grey and black. These shades include platinum, outer space, quick silver, eerie black, and dark silver. They are caused by the numerous high-rises in this city. For Buenos Aires, the dominant colours are shades of brown and grey. These shades are khaki (HTML/CSS), black chocolate, shadow, dark puce, and bright grey. These colours are due to the roads, buildings, and their shadows. For Lima, the dominant colours are shades of grey. They include Davy's grey, quick silver, grey (HTML/CSS Grey), Charleston green, and Gainsboro. These colours are due to the buildings and the mountainous terrain.

The results also show that there are similarities among the dominant colours for these twelve cities, even though they are spread across six continents. Light cobalt blue and sonic silver are the colours with the highest frequencies. These two colours are observed in three cities. Light cobalt blue occurs in Cape Town, Perth, and Singapore because they are all coastal cities. Sonic silver is found in Cape Town, Perth, and Sydney because these cities have many skyscrapers.

On top of that, Perth is a major industrial centre. Ten colours occur in pairs of cities. These include raisin black, olive drab camouflage, Charleston green, Gainsboro, outer space, khaki (HTML/CSS), eerie black, platinum, quick silver, and shadow. Raisin black is found in Cairo and London. Olive drab camouflage is found in Cairo and Mexico City. Charleston green is observed in Singapore and Lima. Gainsboro is also seen in Singapore and Lima. Outer space occurs in New York City and Tokyo. Khaki (HTML/CSS) is seen in Buenos Aires and Madrid. Eerie black occurs in Mexico City and New York City. Platinum is also seen in Mexico City and New York City. Quick silver is found in New York City and Lima. Shadow occurs in Madrid and Buenos Aires. Some of these cities even have two out of five dominant colours in common. Madrid and Buenos Aires have shadow and khaki (HTML/CSS) colours. Cape Town and Perth have light cobalt blue and sonic silver. Singapore and Lima both have Charleston Green and Gainsboro, while Mexico City and New York City have eerie black and platinum.

VI. CONCLUSIONS

This investigation determined whether there are similarities in dominant colours for cosmopolitan cities. Colours add charm to cities, and they are affected by four factors. These include when these cities were established, climate, city ordinances, and cultural heritage. Colour extractions were executed using FCM clustering with 5 clusters on downloaded images of twelve cities that are dispersed across six continents. These cities include Cairo, Cape Town, Singapore, Tokyo, Perth, Sydney, London, Madrid, Mexico City, New York City, Buenos Aires, and Lima. Results showed that there are commonalities among the prominent colours for these cities. The two colours with the highest frequencies are light cobalt blue and sonic silver. They are found in 25% of the cities that were studied. Ten colours occurred in pairs of cities. They are raisin black, olive drab camouflage, Charleston green, Gainsboro, outer space, khaki (HTML/CSS), eerie black, platinum, quick silver, and shadow. The most significant finding shows that some cosmopolitan cities have two out of the five dominant colours in common. Madrid and Buenos Aires have shadow and khaki (HTML/CSS) in their colour schemes. Cape Town and Perth have light cobalt blue and sonic silver. Singapore and Lima both have Charleston Green and Gainsboro, while Mexico City and New York City have eerie black and platinum. These dominant colours could be used to create colour palettes for each of these cities so that new construction projects would be designed in harmony with the existing colour pattern of these locations. In addition, the methodology for creating colour palettes for these 12 cites could be applied to other locations to obtain colour schemes for them. Future studies involve evaluating dominant colours of other cosmopolitan cities using other types of clustering methods to include K-means clustering and Quick Fuzzy C-Means clustering.

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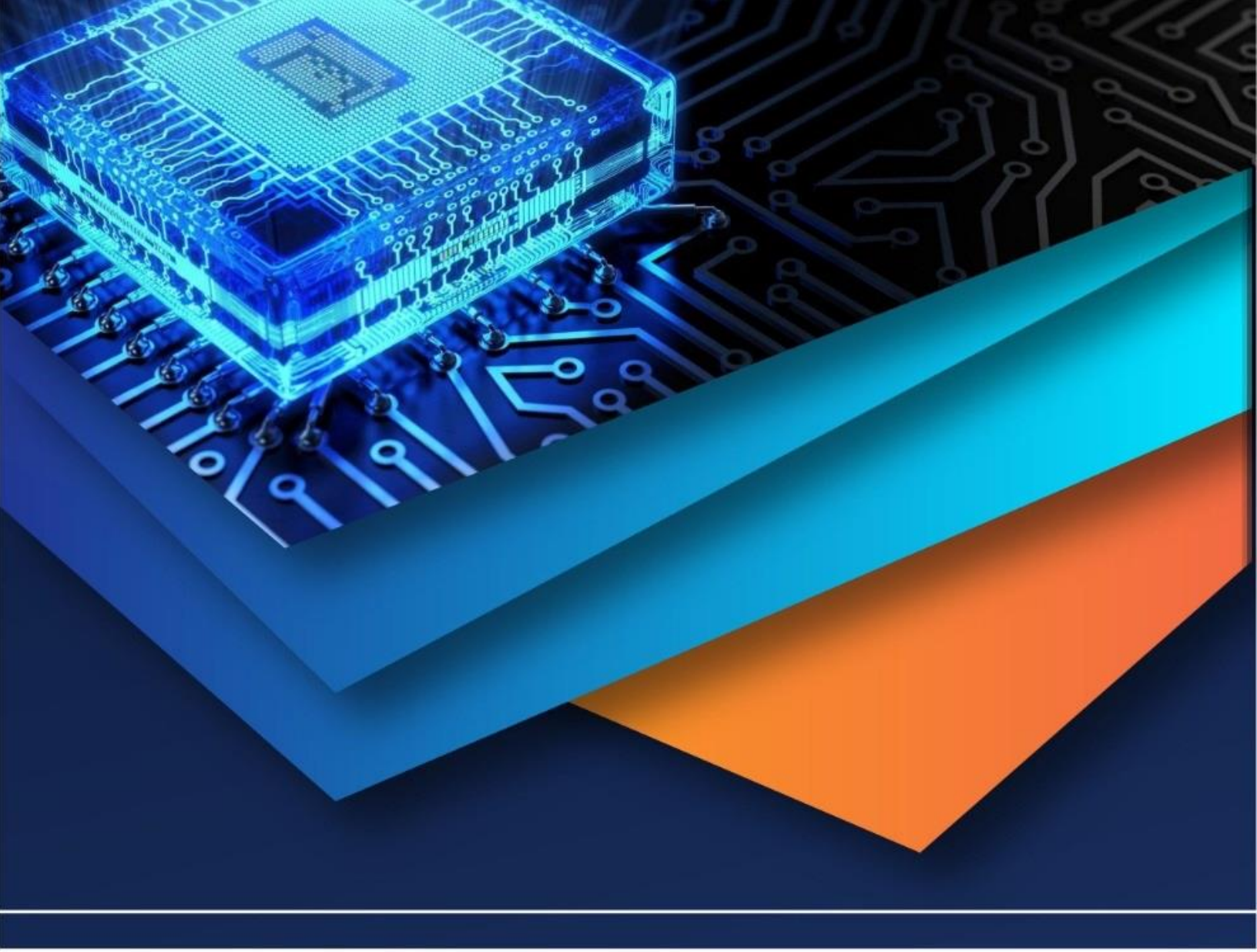
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