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AI-Based Environmental Color System in Achieving Sustainable Urban Development

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Abstract: Confronting the age of artificial intelligence, exploring art through technology has become one of the directions of interdisciplinary development. Not only does artificial intelligence technology explore sustainability on a technical level; it can also take advantage of itself to focus on the visual perception of the living environment. People frequently interpret environmental features through their eyes, and the use of intuitive eye-tracking can provide effective data that can contribute to environmental sustainability in managing the environment and color planning to enhance the image of cities. This research investigates the visual responses of people viewing the historic city of Macau through an eye movement experiment to understand how the color characteristics of the physical environment are perceived. The research reveals that the buildings and plantings in the historic district of Macau are the most visible objects in the environment, while the smaller scale of St. Dominic's Square, the Company of Jesus Square, and St. Augustine's Square, which have a sense of spatial extension, have also become iconic environmental landscapes. This also draws visual attention and guides the direction of travel. The overall impressions of the Historic Centre of Macau, as expressed by the participants after the eye movement experiment, were mainly described as "multiculturalism", "architectural style", "traditional architecture", "color scheme", and "garden planting". The 60 colors representing the urban color of Macau are then organized around these deep feelings about the environment. Therefore, for future inspiration, the 60 colors can be applied through design practice to create color expressions that fit the local characteristics, and thereby enhance the overall visual image of the city.

Keywords: historic centre of Macau; environmental color; eye movement experiment; visual focus; artificial intelligence

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1. Introduction

According to the United Nations Educational, Scientific and Cultural Organization (UNESCO), World Heritage can be classified as natural and cultural heritage, with the latter distinguished into artifacts, buildings, and sites. Following the adoption of the 2030 Agenda for Sustainable Development by the UN General Assembly in 2015, which included culture in the discussion on sustainable development and provided an in-depth analysis of the many ways in which culture can contribute to environmental, economic, and social development [1], the role of heritage conservation and cultural resources in promoting sustainable development should be recognised when it comes to the environmental dimension, minimizing damage to cultural heritage from commercial activities, preserving its historic environment, and maintaining the urban landscape. Economically, in addition to meeting the need for economic development, reducing the impact on the rich traditional cultural environment is also important. Socially, a good historical environment contributes

to the continuation of the urban pattern, the promotion of national culture, and the passing of generations. Furthermore, excavation, exploration and other investigations aimed at discovering, recognising, preserving, and promoting the historic environment should be actively pursued through "scientific and technological" means [2]. In the Asian region, Macau is a tourist city with a thriving economy and a rich cultural heritage. With the gradual settlement of the Portuguese in the mid-16th century and the construction of St. Paul's College and a series of churches, the Historic Centre of Macau took shape as a city of churches and European-style buildings and is now part of the World Heritage List. Witnessing the development of Western religious culture in China and the Far East, the Historic Centre of Macao is the oldest surviving heritage of Western-style architecture in China, a synthesis of the architectural arts of east and west. As the first permanent base of a European nation in East Asia, the city has witnessed over 400 years of mutual exchange and diversified coexistence between Chinese and Western cultures in Macau. According to Ramírez-Guerrero et al. [3], World Heritage is a combination of social, tourism, heritage, and sustainable development that can improve people's attitude towards their living environment. In the Historic Centre of Macau, both the living, passing, and commercial streets and the squares (or foregrounds) that link them create a spatial character with variability. A preliminary understanding of people's concerns about the geographical location of street spaces, their surroundings, and people's feelings can also serve as a basis for improving the environmental landscape [4]. In urban landscapes, architectural colors are also an integral part of urban culture and style, which influence the mood of urban residents [5]. According to Zhang and Chan [6], the color characteristics of distinctive buildings are easily reminiscent of realistic architectural landmarks, reinforcing the impression of urban character. In general, the color of the urban environment can be said to be an expression of the overall urban body.

Color, as one of the dimensions of visual communication, plays a crucial role in people's place identity and environmental experience [7]. Simultaneously, it is involved in a wide range of fields and scopes, such as the changing seasons of nature and even human-constructed architecture. According to Huang and Kobayashi [8], exploring the phenomenon of color presence in the environment can be based on the relationship between environmental color and local culture and history; thus, we understand how color is represented. Conversely, with the prevalence of globalized industrial materials, architectural colors in cities will almost inevitably be similar. However, it is worth noting that color continues to maintain the character of the city in a symbolic form [9]. Moreover, with the help of imaging science, it is possible to clearly understand the parts of the environment that receive more attention. For example, Papinutto et al. [10] Used eye movement technology to perform a series of sweeps of the environment to provide observational information to the visual system. Consequently, areas of interest in the physical environment are obtained to understand people's visual motion directions and preferences, which can guide planning for environment design. This research investigates the core areas of the historic city of Macau and scrutinizes and analyzes the environmental colors thereof. The range of colors will hence be summarized to form the environmental color system of the Historic Centre of Macau. Additionally, this research focuses specifically on the visual response history of people when viewing environmental places and applies it to distinguish the visual focus and area when viewing scenes. The study methodology mentioned above will help the extension and development of artificial intelligence technology in areas related to image identification and provide a greater emphasis on aesthetics in environment constructions. Thus, the research can thereby analyze the color range of the urban area in a more procedural way and provide a more precise reference for urban planning and color design practices.

2. Related Work

2.1. Ways to Explore the Characteristics of the Urban Environment

For design research, if we want to clarify the social phenomena or problems, explore the vision of design needs, and the possible impact of design on society, we need to make a visual summary of the current situation by expanding the scope of needs. From a basic phenomenological perspective, the researcher discusses what constitutes an intelligible phenomenon, the characteristics of objects, and symbols of things [11], and whether these latent meanings have deeper significance. For example, what meaningful messages can be provided by the hidden clues of color in the environment? Thus, in the field, the approach to understanding the nature of empirical phenomena is, as Køster and Fernandez [12] mention, the idea that phenomenology is concerned with experience, subjectivity, and the life-world. Moreover, many disciplines transform it as a paradigm for qualitative research into an empirical approach that facilitates interviews and data analysis. Hawkins [13] also discusses the relationship between landscape, viewing, and sense of sight from a cultural geography perspective, working on how people perceive the urban landscape in terms of objective visual images, and thus understanding the social aspects and values of landscape presence. Moreover, people's imagination and understanding of the geographical environment also suggest the total concept of constructing the sensitivity of the world [14]. As far the landscape is concerned, the relationship between the imagination and the imagined is intimately close because visual and aesthetic perceptions play a key role in understanding the geographic imagination and landscape.

The Historic Centre of Macau, with its historic architecture and colors, is a symbol of the reproduction of an exotic culture. This icon, which can be seen as a cultural landscape, can take the form of pictorial messages that reveal what people want to see, and image-making techniques have naturally played an important role in the modernization and urbanization process, especially in understanding how vision works—letting the intuitive eye do the talking—and demonstrating the importance of research as to how things are seen [15]. As some visual research indicates, visual stimulation can be used to further understand how people view objects, and the object characteristics can obtain the stimulus time and affected factors from visual feedbacks [16]. By doing so, it will affect people's judgment of the existing phenomenon, and then form the feelings, which suggests the changes of mood [17]. The interplay of environmental color and atmosphere and visual messages and communication is explored using phenomenological concepts based on Heidegger's philosophy. By gaining insight into the combined discussion of phenomena (environmental state), atmosphere (place identity), and form (compositional expression) that people make when they focus on the environment and what they focus on, the current characteristics of the environment can be summarized and described, thus resolving the specific elements of the color image of the city within the place (Figure 1). As intentionality is the basic structure of human consciousness, when the activity of the mind is connected to a viewing object, people will direct their eyes towards that object. Thus, observing and dissecting the context in which an image or color is seen requires experience and memory to re-present the characteristics of the place, not only to illuminate the impact of the environment on people, but also to understand the feelings and perceptions between people and the environment.

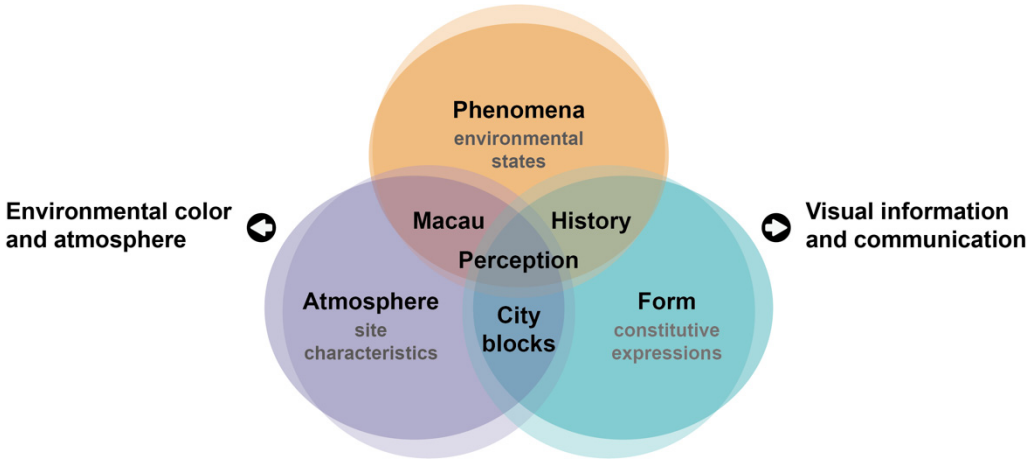

Figure 1. Architecture of the analytical model used in this study.

2.2. Environmental Color and Atmosphere

Color, in addition to having a pluralistic appearance, varies according to geography. Samalavicius [18] mentions that context, climate, and culture determine the use of color and influence people's experience thereof, especially the color of a particular place or situation, and the qualities of the air can lead to a specific concept of color. Additionally, different cultural backgrounds bring about the formation of unique preferences for individual colors, one example of which is the Chinese preference for the color red. Thus, cultural factors also make a difference in people's choice of colors for objects [19]. According to City Making: Nine Principles of Urban Design for the 21st Century, creating urban diversity and compatibility can be achieved by preserving notable landscapes, historic street patterns, and interesting historic buildings; in particular, the guidelines for architectural color state that light-colored buildings reflect the state of shadows and sunlight, creating a sense of compatibility with other building groups [20]. The book, Urban Design: Streets and Squares, also mentions that the primary character of the street depends on the treatment of the spatial body, but the atmosphere of the street and its character is determined by the buildings [21]. For example, the buildings along the Rio Douro are painted in a variety of bright colors (white, red, and yellow), which help to attract the attention of visitors (Figure 2). To use colors in the environmental design can not only have significant visibility, but also provide effective visual information for people by designing the color difference between objects and the environments [22].

Figure 2. The architectural colors on the left bank of the Porto Douro in Portugal create a romantic atmosphere, and the public spaces of the city are planted with tulip herbs to create a pleasant environment.

According to Skaržauskienė and Mačiulienė [23], highly used plazas in cities have a variety of colors, textures, and landscape elements, so the color is a key factor for plaza users' enjoyment, and annual or perennial trees and flowering shrubs in planting beds create a pleasant environment. A study on emotional scenes and visual attention revealed that people's emotional factors exert an influence on their psychological perceptions when

viewing environmental objects, which appears to support the point that the object being viewed or the content of the environment influences people's emotions [24]. According to Damle and Smith [25], color factors contribute significantly to design perceptions and even bring different perceptual responses, such as mood, ambience, and state. Clearly, in urban plazas, all buildings and plantings are highly visually appealing. In addition to harmonizing with the urban landscape enclosed by the streets and squares, the colors attached to these objects reflect the components of the urban message, creating a semi-enclosed state of place identity. Such scenic content undoubtedly provides people with a better sense of experience of the environment.

2.3. Visual Information and Communication

People's eye movements can be one of the important topics in the research of computer vision, especially the application to the human–environment interaction [26], so as to improve the environment and achieve the goal of sustainable development. Since people process most of their sensory information visually to perceive their surroundings and communicate it to the brain through the optic nerve to recognize the physical environment, it is possible to understand people's internal psychological responses by observing eye activity. Bálizs [27] mentions that memory affects people's recognition of colors; for example, some colors are more easily perceived than others, especially yellow and green. In a study of active or cold building façades along streets, it was concluded that people's eyes observe environmental features in a horizontal direction, and that the eye absorbs information within the visual horizon, so that open street storefronts, with their mixed and diverse functional design, are more attractive and can increase the activity of people within the environment [28]. Nowadays, research techniques for observing eye movements to explore people's psychological journey are quite well established. Among them, Dowd and Golomb [29] argued that observing people's visual responses can indeed directly infer cognitive processing in the brain; e.g., the trajectory of vision when viewing something can reflect the focus of visual attention, and thus infer attitudes and preferences for viewing objects. While interpreting the information visualization, people do not simply accept the external information. In contrast, people have different biases or expectations about how visual features are interpreted into meaning, so as to lead and direct the interpretation of visual information [30]. Therefore, the analysis of people's behavior in viewing environmental images can be used to further understand color features and visual focus and to interpret the relationship between them.

3. Research Method

To conduct research in Macau, it is first necessary to understand the city's urban characteristics, historic urban area, and architectural landscape. Then, the research objectives are completed by using environmental color, eye movement, and other technologies. As for the research process, the Tobii Pro x3-120 (sampling rate 120 Hz) screen eye tracker is used to screen subjects who had not previously visited Macau. Moreover, subjects must pass the Ishihara color test to ensure that they can accurately identify different hues. The research scope focuses on 8 squares in the Historic Centre of Macau (Figure 3), this part comprises the creation of banner images of various squares for eye-movement experiments in the laboratory, including the surrounding buildings, plants, and ground pavements. Additionally, three other street scenes in Macau were selected as early experimental observations (Figure 4). These street scenes reflect the historical urban area and commercial blocks and are also public places formed through formal planning in the process of urban development in Macau. These were chosen to understand the subjects' feelings about the street scenes in Macau.

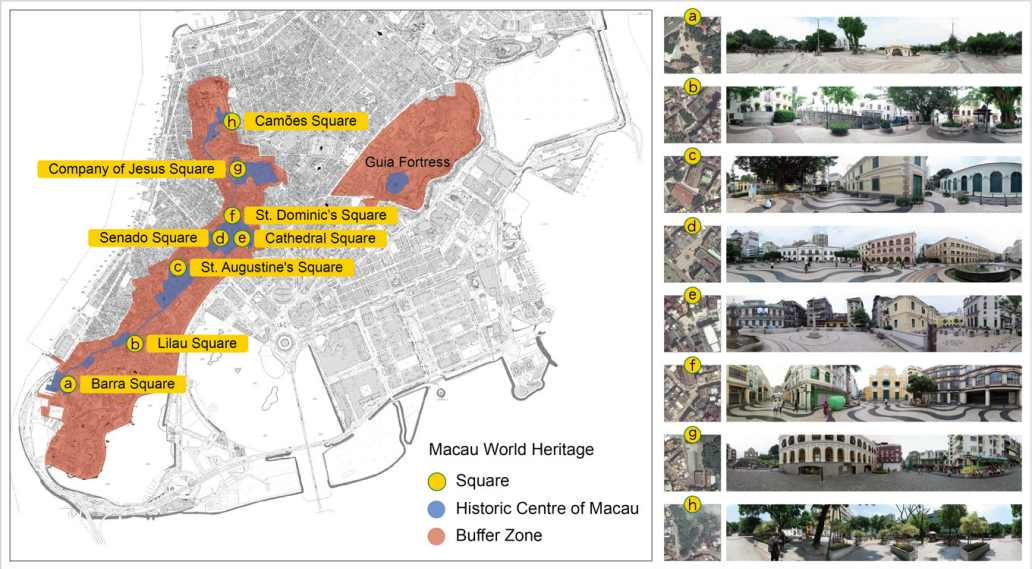

Figure 3. The spatial distribution of eight squares in the Historic Centre of Macau and the panoramic view and development of each square.

Figure 4. The eye movement technique was used to analyze the attention of characteristic street scenes in Macau. It was found that both the characters and the advertising signs affected the subjects' fixation. In view of this, in the next phase of the experiment in the Historic Centre of Macau, the subjects will be first told to avoid looking at people and advertising objects as much as possible.

In this research, 30 students (No. 01–30) from Huaqiao University participated in the test, comprising 12 males and 18 females, with an average age of 21 years, who met the standard of experimental conditions. Prior to the experiment, participants were told to avoid looking at people and advertising signs while viewing images of the environment, in order to reduce distractions. When the test completed, supplemented by a retrospective interview, the semi-structured interview was carried out as follows:

- Which places impressed you the most when you saw the eight squares in the Historic Centre of Macau?
- What objects are you particularly interested in when looking at the environmental content?
- What scenery would you like to revisit after seeing these squares?
- Describe the objects you are particularly interested in, e.g., features or color appearance;
- Please describe your overall impression or feeling of the Historic Centre of Macau.

After completing the eye-movement viewing experiment, the author compiled the results thereof, together with the interviews, followed by a field survey to collect the environmental content of the subjects' concerns, and then collected and summarized the representative colors of the historic district of Macau. This research used the 2014 edition of the Pantone Formula Guide (uncoated paper-based color cards) with the Pantone CapSure color measuring instrument. The color survey was conducted in groups of three to avoid individual subjective judgments. During the research, the color cards and objects were kept in the same light environment as much as possible, so that they were not affected by changes in the light source. After collecting the color samples of the environmental landscape, color was analyzed and summarized through field records, instrument color measurement, color card comparison and subsequent elimination of duplicate hues, color value descriptions, color coding, and color group archiving.

In conclusion, the analysis of environmental factors combined with artificial intelligence technology for color recognition is still focused on promoting the conservation and renewal of architectural colors in historic districts, shifting previous research thinking toward more open and interactive public participation. In the future, it will improve the user's intuitive perception and experience of urban color when paired with virtual reality experiences.

4. Result Analysis and Discussion

4.1. Environmental Color and Atmosphere of the Historic Centre of Macau

According to the official definition of Macau, the Historic Centre is broadly defined as the area of monuments, buildings, clusters of buildings, and places with significant cultural value, and architectural and artistic value [31]. For instance, constructed in 1644, the Ruins of St. Paul's was also the first Baroque building in China. Combining traditional Chinese figurative stone lions, Chinese characters and chrysanthemums, a symbol of Japan, with classical European elements in its construction, the front wall represents the expression of Catholic architectural art in the Far East and reflects the east–west cultural mix in Macau's history. For the historic district, it should simultaneously have many historic buildings, a representative historic landscape, and an intact or remediable visual environment. Among them, "historic landscape" refers to the style, image, material, color, and topography of buildings and structures, reflecting the traditional landscape characteristics of the place in a certain historical period [32]. A look at the heritage buildings in the Historic Centre of Macau reveals that they are mostly colored in gray, white, yellow, and green (Figure 5), and there are mainly two colors used for the architectural elevation, such as the Lou Kau Mansion, the Casa Garden, the St. Lawrence's Church, and the Dom Pedro V Theatre. The survey reveals that the historic district of Macau is dominated by gray colors. It is also dominated by gray tones, such as the Memorial Arch of A-Ma Temple and the Ruins of St. Paul's. Using granites as the building material, it is also known as pockmarked or hemp stone due to its characteristic mixture of tiny black and grey dots, which create a grey-like color when viewed from a distance. The color painting method makes the buildings in the city appear to have a clean, elegant, and plain style, such as St. Lawrence's Church, St. Joseph's Church, St. Augustine's Church, and the St. Dominic's Church, all with yellow tones as the main color. The color of the windows and doors of these European-style buildings is generally green, with a hue close to dark green, which also constitutes one of the characteristics of the imitation of European-style architecture in Macau.

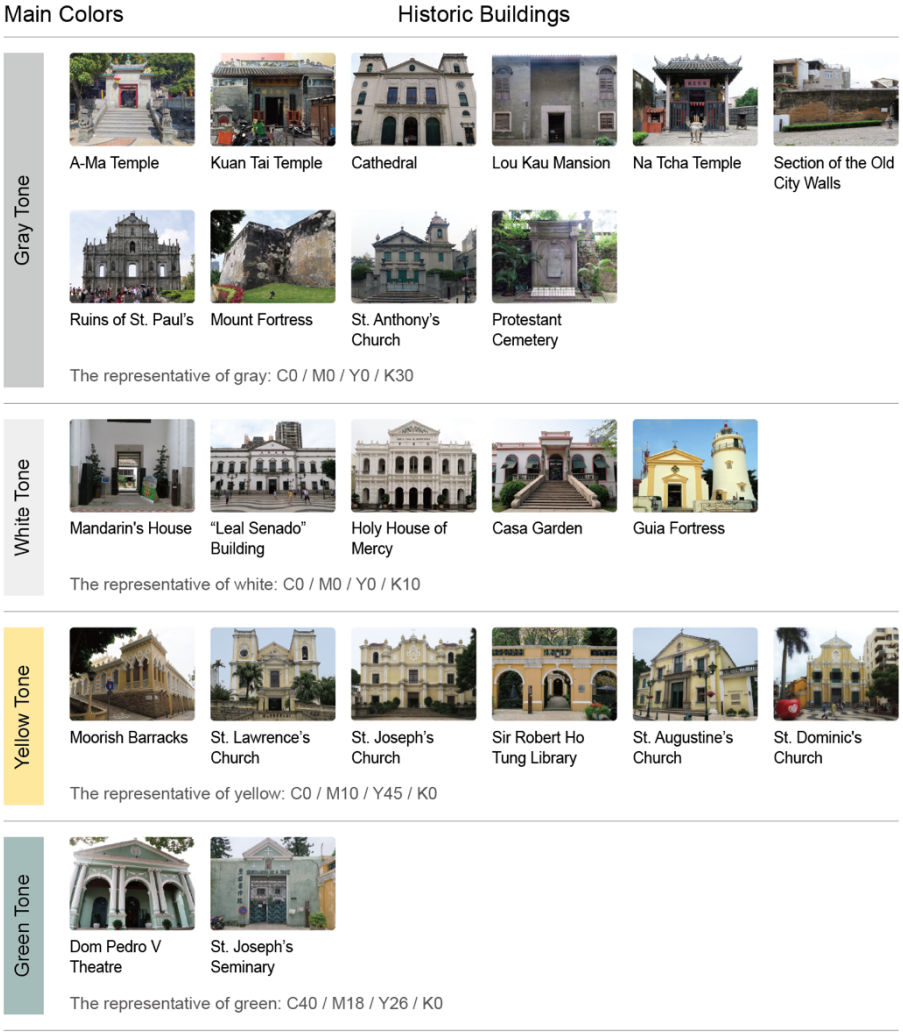

Figure 5. Main colors of historic buildings in the Historic Centre of Macau.

4.2. Visual Information and Communication of the Historic Centre of Macau

Eight square spaces in Macao's historic city center were photographed panorama-style and turned into images based on their central location. Then, 30 subjects were tracked through eye movement to further analyze the preferences of the objects they looked at. After analyzing the eye movement data, it was found that subjects generally focused on buildings and plants, but could not completely eliminate objects in the environment, especially public facilities, advertising objects, and people. When looking at the content of the environment, people will not only be attracted by the close-range objects and pay attention to the relatively large single buildings in the environment, but also pay special attention to the angle space in the distance. This phenomenon occurred in smaller squares and urban streets adjacent to compact residential buildings, which was also caused by participants' curiosity.

Excluding the interfering objects in the staring environment, the analysis found that the most concentrated objects of Barra Square are the sightseeing boat wharf, Memorial Arch of A-Ma Temple and surrounding green plants (Figure 6a). The Portuguese residential buildings around Lilau Square attract the most attention, followed by plantings (Figure 6b); St. Augustine's Square is the most popular European-style building, with a distant corner street view, followed by Dom Pedro V Theatre, St. Augustine's Church, etc. (Figure 6c). Senado Square attracts the most attention with Lear Senado, Koi Kei bakery, Macau business tourism center, etc. (Figure 6d). Cathedral Square's decorative patterns of St. Dominic's houses, Macau Diesel's epic office, fountain, and cobblestone road can be seen in Figure 6e.

St. Dominic's Square attracts the most attention with the St. Dominic's Church and the surrounding European-style buildings, as well as Lear Senado (Figure 6f) with a corner street view in the distance. The Company of Jesus Square is the most concentrated at the Ruins of St. Paul, Houses of No. 4 and No. 6 (Figure 6g), and, at Camões Square, most focus on the surrounding plants, followed by the entrance of the Anglican Morrison Hall (Figure 6h).

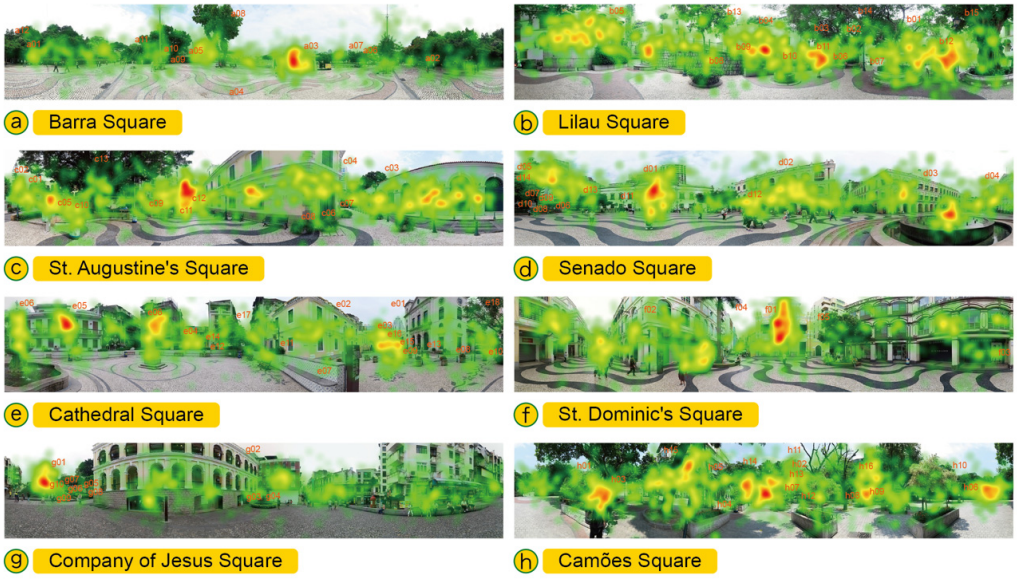

Figure 6. Thirty subjects were tracked by eye movement to watch the target objects in eight square spaces in the Historic Centre of Macau.

After the eye movement experiment, retrospective interviews were conducted to reconfirm and understand the participants' perceptions of the historic district of Macau. From the interview data, participants were most impressed with St. Dominic's Square, Company of Jesus Square, St. Augustine's Square, and Senado Square, and less impressed with Barra Square. This may be because there are fewer objects in the environment. The scenes that caused particular interest to the subjects were the Ruins of St. Paul, the fountain, and the advertising objects. The buildings around these aforementioned plazas were most impressive for their yellow and green architectural appearance, reflecting the church building and the theater on top of the hill, and the green window and door decorations.

After paying attention to the environment, the subjects were inclined to repeat their viewing, including the yellow building of the St. Dominic's Church in St. Dominic's Square, and the green apple-shaped propaganda facility; for example, one of the subjects, No. 18, looked at a specific object for a longer period (Figure 7). By observing his eye movement with a hot spot map and trajectory map, we can see that the color red represents the longest fixation duration, followed by yellow, and the shortest was green. Similarly, we observed the same situation in subjects No. 03, No. 20, and No. 23 (Table 1). The eye tracking software (Tobii Pro Lab) was used to calculate the experimental data, with the following formula showing the subjects' average number and duration of fixations on a specific object (such as the area of interest, AOI) [33].

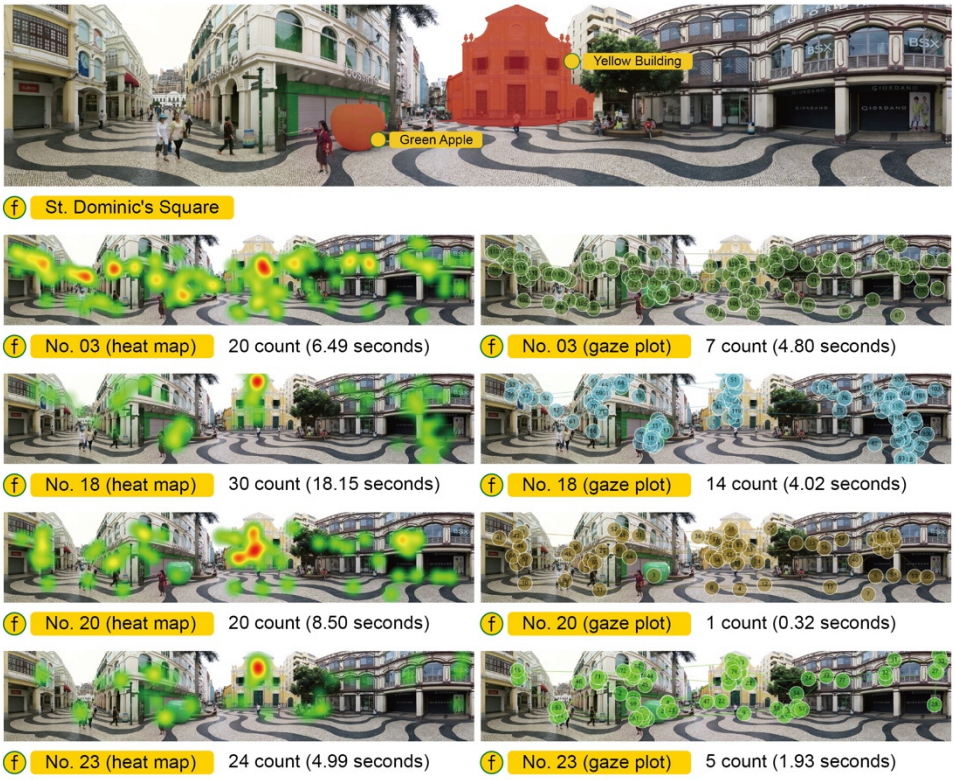

Figure 7. St. Dominic's Square receives the most attention for its yellow buildings and green apples.

Table 1. Thirty participants were asked to look at a specific object using St. Dominic's Square as an example.

St. Dominic's Square	Number of Fixations in AOI (Include Zeroes)		Total Time of Interest Fixation Count	Total Time of Interest Duration
	Yellow Building	Green Apple		
Participant No. 01	19	2	61	22.48
Participant No. 02	12	3	34	14.50
Participant No. 03	20	7	125	44.66
Participant No. 04	10	12	68	29.78
Participant No. 05	5	1	22	7.24
Participant No. 06	12	6	46	15.57
Participant No. 07	10	4	87	28.56
Participant No. 08	19	1	73	27.49
Participant No. 09	10	3	85	30.46
Participant No. 10	16	6	50	16.74
Participant No. 11	8	1	36	11.24
Participant No. 12	4	0	20	11.42
Participant No. 13	8	1	63	19.45
Participant No. 14	11	4	52	17.82
Participant No. 15	12	0	48	18.50
Participant No. 16	20	0	147	47.59
Participant No. 17	8	3	63	23.70
Participant No. 18	30	14	119	68.46
Participant No. 19	7	0	26	8.99
Participant No. 20	20	1	67	24.90
Participant No. 21	11	2	42	12.92
Participant No. 22	4	4	29	10.91
Participant No. 23	24	5	77	30.62
Participant No. 24	10	4	39	13.67
Participant No. 25	13	0	47	14.29
Participant No. 26	15	0	66	20.97
Participant No. 27	11	4	48	19.60
Participant No. 28	12	1	94	25.58
Participant No. 29	7	0	15	4.75
Participant No. 30	7	7	73	28.23
Average	12.00	2.75	60.73	22.37
Percentage Fixated (%)	100.00	75.00		
Variance	74.67	4.25	985.65	175.19
Standard Deviation (n − 1)	8.64	2.06	31.40	13.24

By calculating the average number of fixations (ANF), a normalized value is acquired where the ideal value is 1 (Equation (1), below).

$$\text{Average Number of Fixations on stimuli points} = \frac{\text{detected fixations}}{\text{number of recordings} \times \text{fixations encoded in the stimuli}} \quad (1)$$

The average fixation duration (AFD), which refers to the average time a fixation lasted, is calculated by adding the duration for all detected fixations and dividing them by the number of fixations detected (Equation (2), below,).

$$\text{Average Fixation Duration} = \frac{1}{N}\sum_{i=1}^{N} \text{fixation\_duration}n_i \quad (2)$$

According to the results, the average number of fixations and durations thereof for the yellow building were 12.50 and 3.63 s, respectively, which were higher than the 3.20 and 1.22 s of the green facility (Table 2). Afterwards, a *t*-test examined whether the difference between the two objects was significant (Table 3). The statistical analysis of the mean gaze times showed a *t*-value of 7.218 and a two-tailed significance of 0.001, which is much smaller than the 95% confidence interval reference value of 0.05, indicating that the yellow building was noticed more often than the green facility. It can thus be concluded that the *t*-value is 3.718 and the two-tailed significance is 0.001, which is much smaller than the reference value of 0.05 in the 95% confidence interval. As mentioned above, the main descriptions of respondents' overall impressions of the Historic Center of Macau are "multiculturalism", "architectural style", "traditional architecture", "color scheme", and "garden planting". Adjectives such as "color scheme" and "garden planting" show that architecture and plantings are the color components of the Historic Centre of Macau.

Table 2. The average number of fixations and duration of subjects' fixations at specific objects presented by St. Dominic's Square.

ⓕ St. Dominic's Square	Yellow Building	Green Apple
Number of fixations in AOI (include zeroes)		
Average	12.50 count	3.20 count
Standard Deviation (n − 1)	6.15 count	3.47 count
Duration of fixations in AOI (include zeroes)		
Average	3.63 s	1.22 s
Standard Deviation (n − 1)	3.19 s	1.56 s

Data source: the experimental data were calculated by the Tobii Pro Lab for 30 subjects, in which the number of fixations was generated by the statistics of the eye tracker.

Table 3. *t*-test for the number of fixations and fixation duration on two objects at St. Dominic's Square.

Variables	Homogeneity Test of Variance		Mean Equivalence *t*-Test			
	F Value	*p* Value	*t*	Significance (Two Tails)	Mean Value Difference	Standard Error Value
Number of fixations	7.078	0.010	7.218	0.001 *	9.300	1.288
Fixation duration	1.302	0.258	3.718	0.001 *	2.412	0.649

* $p < 0.05$.

4.3. Environmental Color and Representation of the Historic Centre of Macau

According to the eye-tracking experiment, in addition to the color of the exterior of the buildings, garden plantings are also used to complement and match the architectural expressions in the square space. For instance, there are four species of plants—red strap flowers, Dwarf umbrella tree, New Guinea impatiens and Ehretia microphylla—on the flowering platform in front of the Senado Square. Red strap flowers are composites of

red and green, and the latter three, although they all have green leaves, are distinctly different in color, with the two red flowers of the New Guinea impatiens producing a rich color palette. Such landscape shaping techniques can also be seen in the sloping beds of the Jesuit Memorial Square with Dragon juniper, Duranta erecta, little ruby, African Touch-me-not, and Globe amaranth. The combination of these plants is a common planting in Macau. Based on the site survey, it was found that the plant species in the eight squares were duplicated, and excluding similar architectural colors and plant species, a total of 372 colors were identified for the historical buildings and 261 colors for the garden plants. By eliminating duplicate or similar colors of buildings and plants, a total of 60 colors representing the city of Macau can be obtained. Reviewing how to select the city colors that represent Macau among the many colors, the factors considered will differ depending on the subject, such as the environmental objects that received the most attention and the distracting factors learned from the interviewees, etc. It is important to collate and summarise them in as objective a manner as possible.

Regarding the selection of architectural colors, the research revealed that brown and green are common colors for windows and doors in Macau's historic buildings. For example, regarding the sightseeing boat wharf of Barra Square (Figure 8a-03), Pantone-3302u (green) was chosen to represent the color of windows and doors, while the main color of the Memorial Arch of A-Ma Temple (Figure 8a-01) was Pantone-7527u (gray), but considering the special color of Chinese temple architecture, Pantone-1807u (red) is used as a secondary color instead. The St. Augustine's Church in St. Augustine's Square is a European-style church building (Figure 8c-04), represented by the primary color Pantone-7401u (yellow). Pantone-7415u (red) is the main color, which was also considered an impressive architectural color by the subjects (Figure 8d-02).

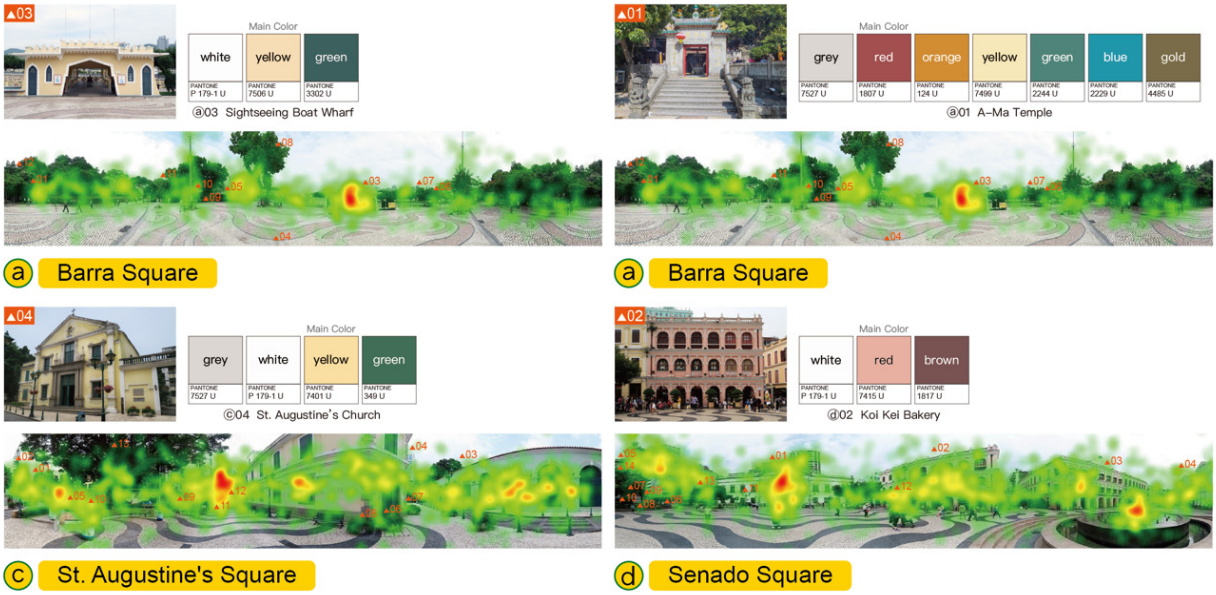

Figure 8. Examples of the selection of main colors of architectural color: sightseeing boat wharf, Memorial Arch of A-Ma Temple, St. Augustine's Church, and Koi Kei Bakery.

The selection of garden color is slightly more complicated than the investigation of architectural color. According to the eye movement experiment and the overall impression of the interviewees, it can be concluded that the garden plants of Lilau Square, St. Augustine's Square, and Camões Square are the most concentrated upon; the design color or leaf color of plants can be considered as the main color. After deleting similar plants, Pantone-3425u (green) (Figure 9b-07) of Dwarf umbrella tree, Pantone-2385u (red) and Pantone-364u (green) (Figure 9a-05) of Ficus microcarpa, Red strap flowers, Dragon juniper, and Catharanthus roseus can be seen. Pantone-225u (red) and Pantone-247u (purple) (Fig-

ure 9h-06) of African impatiens are plants planted in large numbers, which can also be said to be common colors of garden plants in Macau. In view of this, when selecting the main color of the plants, the flower color should be given priority, and if it is not flowering, the leaf color should be seen as supplemental. The more special ones, such as New Guinea impatiens and African impatiens, have different designs and colors. For example, Jungle fire plant is also a similar case, with its single leaf having positive and negative colors. Therefore, these designs and colors are also included.

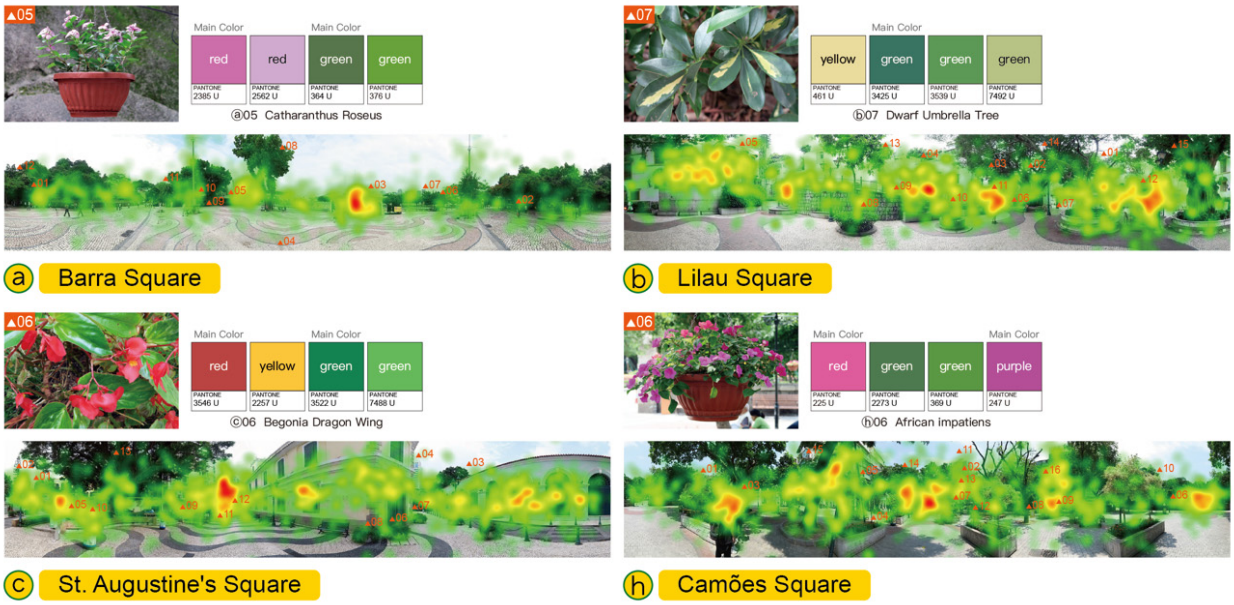

Figure 9. Examples of the main colors for selection of architectural color: Catharanthus roseus, Dwarf umbrella tree, Begonia Dragon Wing, and African impatiens.

The Pantone Formula Guide Uncoated color system can be used as the basis for the construction of the urban colors of Macau, with not only the Pantone color codes but also the CMYK printed color values. Additionally, to distinguish the sample codes of the survey process according to different fields, the 60 colors of Macau urban color (Figure 10) are also coded with the abbreviation MO. For example, MO-01 to MO-22 are the colors of historical buildings, and MO-23 to MO-60 are the colors of garden plants.

In conclusion, the digital capture of environmental color in the Historic Centre of Macau and environmental color concerns and visual preferences summarized through eye-movement experiments have been implemented to achieve a fusion between specialization and popularization through the use of contemporary artificial intelligence in environmental color digital technology, which may serve as a reference for future design practice.

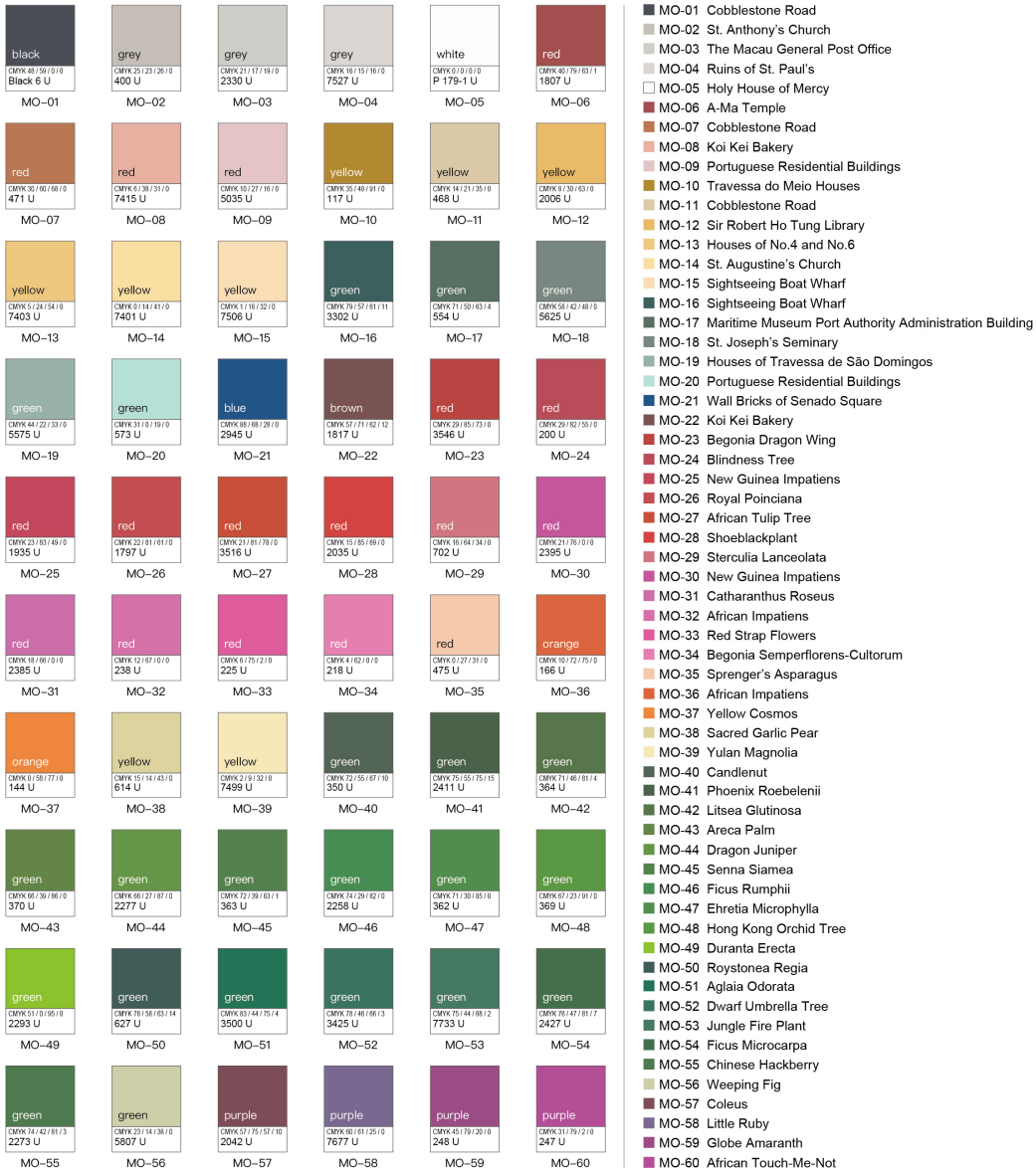

Figure 10. Sixty colors of Macau city.

5. Conclusions

In order to maintain the identity of the historic district as a place, the government of the Macau Special Administrative Region (MSAR) continues to encourage the discovery and use of cultural resources from the environment, with the expectation of continuously enhancing the overall image of the Historic Centre of Macau. With the help of an eye movement experiment, this research analyzed the expression of place composition from the objects in the environment, on which the participants focused and generalized the color system that represents the city of Macau. It can therefore be concluded that buildings and plantings are the most easily viewed objects in the environment. The Historic Centre of Macau is listed as a World Heritage Site, and the color expressions of heritage buildings constitute the characteristics of places, forming the current state of the environment, with plantings matching the buildings. In particular, the smaller St. Dominic's Square, the Company of Jesus Square, and St. Augustine's Square, which have a sense of spatial extension, impressed the participants the most. After the eye movement experiment, the main keywords that the participants expressed as their overall impression of the Historic Centre of Macau were "multiculturalism", "architectural style", "traditional architecture",

"color scheme", and "garden planting". These impressions of the environment can be grouped into two categories: one is the relatively common architectural color scheme with 3 or 4 colors, with the most common combinations of three colors being white, grey, green and brown, such as St. Joseph's Seminary, the "Leal Senado" Building, the Macau General Post Office and St. Antho-ny's Church; the other category is a four-color combination, mostly white and yellow, such as the Sir Robert Ho Tung Library and St. Augustine's Church and Casa Garden. Most of the garden colors are in four-color combinations, especially red, yellow, green and purple, such as Catharanthus Roseus, Begonia Dragon Wing, Shoeblackplant, African Impatiens, as well as variegated foliage plants with a wide range of colors, such as Dwarf Umbrella Tree, Coleus, Duranta Erecta, Weeping Figure.

The composition of environmental colors not only reflects the characteristics of the place in the historical city, but also forms a kind of iconic environmental landscape, which also draws visual attention and guides the direction of travel, becoming a visual dynamic influenced by the environmental palette. Given that visual space is created and constituted around a series of objects in space, Macau Urban Color 60 is the result of a survey of the colors of historic buildings and garden plants at a specific time and place, and the selection of hue groups that represent the color of the city. Color has always been a means of highlighting the image of a city, and the purpose of urban color construction is to discover the color state of existing spaces and to sort out the color patterns hidden in the environment. However, it is indispensable to apply this to design practice, which ultimately enhances the visual image of the city as a whole. To sum up, the eye movement experiment is used to obtain the more concerned objects in the environment, thus obtaining effective visual information, and analyzing the relationship between people's attention and visual preference and architectural color. In the future, we will make further beneficial exploration for image recognition in complex environments, hoping to help extend and expand the field of artificial intelligence.

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