PROCEEDINGS OF SCIENCE

Some study results of color changes depending on Mongolian environmental condition

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We started a color experiment, which is tried to obtain the method studying quality of colorants and color fading of objects. This long-term color measurement can be used to determine how the colorants change by environmental influence, and to develop the methodology for such analysis will predict the initial object color. This will allow the cultural heritage to be restored by its original color, as well as to determine which colorants have the least changing and the most durable. Therefore, in this study we prepared a measurement object to analyse color fading, performed long-term and short-term measurements weekly for five months. Processing of the measurement results shows that most of the pigments have faded and most of the dye were stable, but the white dye changed the most. It is possible that the change depends on the absorption of the color spectrum. In the next research we have increased the measurement objects, so the data analysis will be more precise, and the aim is to forecast the initial color of the object using a machine learning approach based on regression analysis by more color measurement values.

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1. Introduction

In recent years, the field of color studies has developed into an independent science around the world, and research using color technology has been intensified [1,7]. The color science [2] is developing in conjunction with all disciplines such as cultural heritage, medicine, agriculture, aerospace, computer science, image processing, and the environment . In addition to the theoretical study of topography, we aim to introduce color technologies to Mongolia and use them in the field of cultural heritage.

The purpose of our color experiment is to study the color quality and color fading of ancient buildings. As part of this task, this article describes a color analysis and the method used to study color fading on dyes and pigments [3] commonly sold in Mongolia. It is possible to predict the initial color of an object by long-term color measurements and to develop the methods to determine how its changing of the colorants [12] depends on the effects of the environment by color analyzes [14]. This will allow the cultural heritage to be restored to its original color, as well as to determine which colorants have the least changing and the most durable.

We measured the color with the value L * a * b * [4] according to the color measurement methodology [3], and analyzed the data using the linear regression analysis method [15] depending on the time to study the color fading in the color values of this measurement [6]. Because it is intended to study color fading, it is analyzed using the measured L * a * b * values (called CIELAB, CIE is the International Commission on Illumination, and LAB is the name of the color space) is the most suitable and popular for measuring object color [1]. It was released by the CIE in 1976. L * a * b * is the color of the luminosity instead of L *, and a * and b * are the chromaticity or color coordinates [4, 5]. There are many works in the field of color studies, but this kind of study is implemented the first time in our country that colorant is analyzed by calculated numerically.

2. Materials and methodology

2.1. Measuring sample:

Measuring sample were made of four pigments of red, green, blue, and yellow, and five dyes of red, green, blue, yellow, and white [1,3]. Preparing this object, we have install the special board to measure one stable coordinate for colorimeter. And we installed it in the roof of our institute in Ulaanbaatar on February 2020.

Figure 1. Color measurement sample with 9 colors

The following table summarizes the origins of colorants and whether they are dyes or pigments.

Table 1. Colorants of measurement objects

№	Colorants	Origin
1	Red pigment	Korea
2	Green pigment	Korea
3	Blue pigment	Korea
4	Yellow pigment	Korea
5	Red dye	Russia

6	Green dye	Russia
7	Blue dye	Russia
8	Yellow dye	Russia
9	White dye	Russia

2.2. **Measurement methodology:**

In addition to the color measurement methodology, the study was performed according to the following general methodology [15].

Figure 2. Color analyzes sequence

The measurements were made using a color measuring instrument called X-rite i1 Pro Colorimeter [8] or a portable spectrophotometer according to the following color measurement method [9].

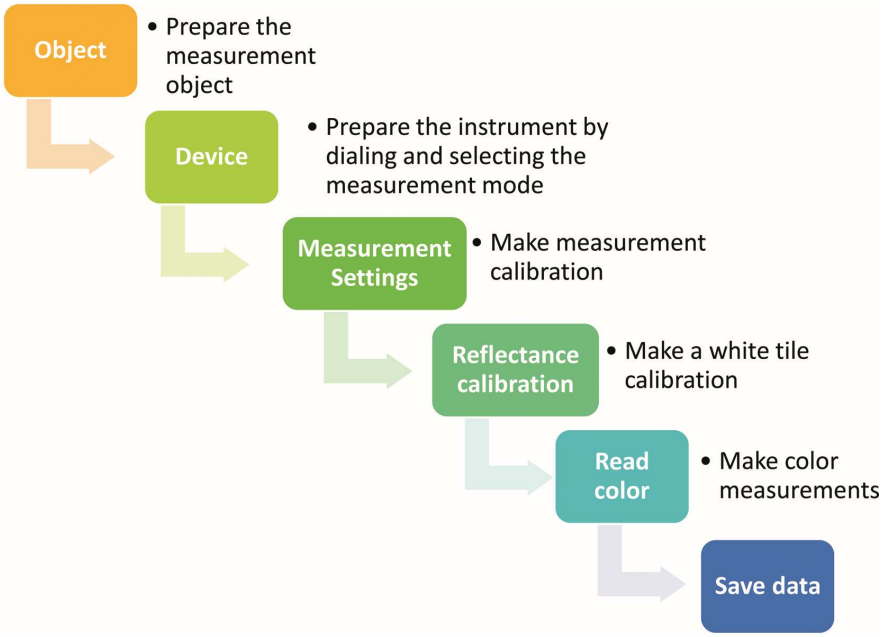


Figure 3. Color measurement sequence

First, prepare the measurement object for measurement, connect the instrument to the computer to be measured via USB, and connect the appropriate base according to the measurement procedure. For us, the measurement is measured by the Spot color measurement mode of any object. The Patch Tool software, which works with the X-rite i1 Pro Colorimeter, sets the measurement by adjusting the number of measurements, the measuring device, the measuring condition, or the illumination. Then we have to calibrate white tile calibration. Then the instrument is ready for measurement. When the it has finished, save the measurement value [10], select the color data types you need in the settings section, select the spectrum size, and name the measurement file [8,9].

We performed the measurements a total of 14 times a week from February to June. In this study, single-point measurement values are considered, as shown in the following graphs [14].

The color values are arranged along the Y axis, and the measurement period is arranged in the order 1 to 14 weeks along the X-axis. The R^2, which is one of the variables in the regression analysis, is calculated by the following formula [15].

$$R^2 = 1 - \frac{SS_{RES}}{SS_{TOT}} = 1 - \frac{\sum_i (y_i - \hat{y}_i)^2}{\sum_i (y_i - \overline{y})^2}$$

Formula 1. Formula of R^2

SSregression is the sum of squares resulting from regression, and SStotal is the sum of squares.

Also we calculated the color difference ΔE by following formula [6].

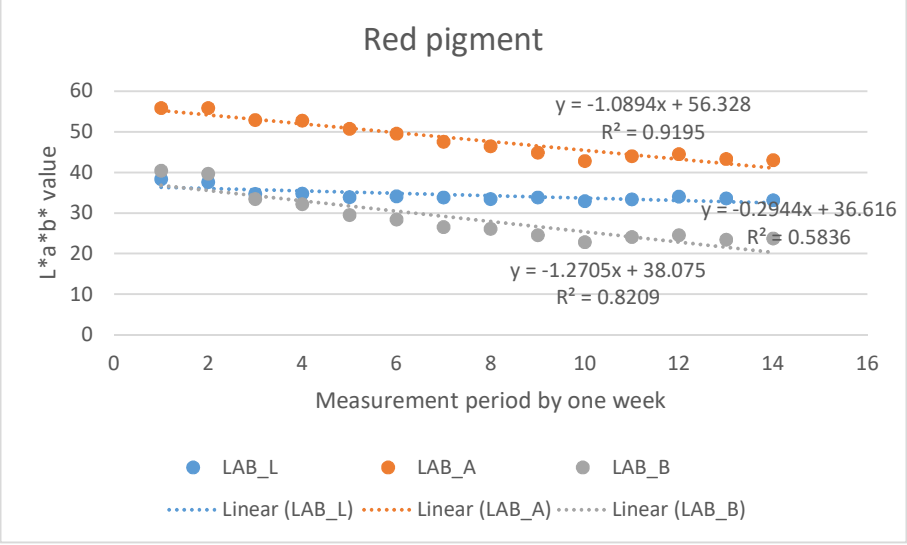
$$\Delta E^*_{ab} = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}.$$

Formula 2. Formula of color difference

3. Results and discussion

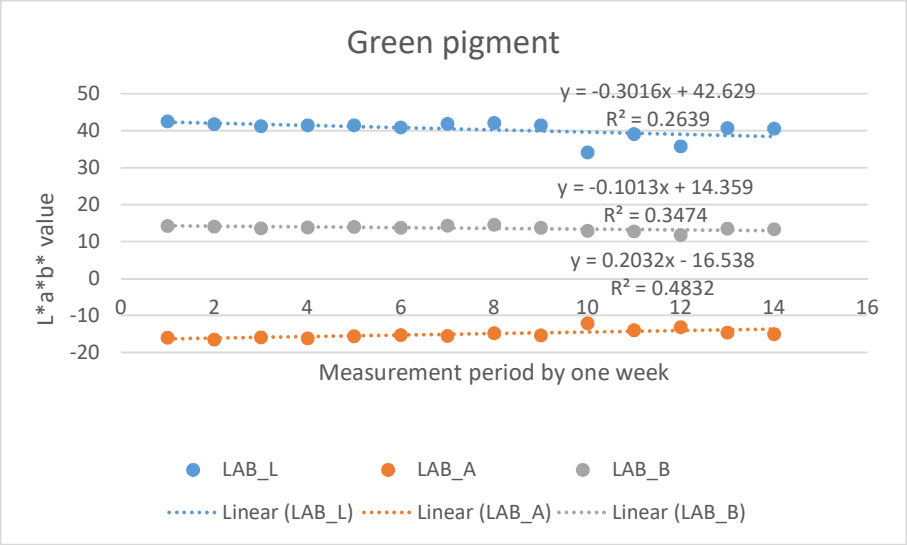
We calculated R^2 using the Excel data analyzes tool. The following graphs show the period-dependent color change by the linear regression method [14,15]. Since L* is the value for whiteness, the fading index is generally considered to be the change in L*.

Results of color change and fade:



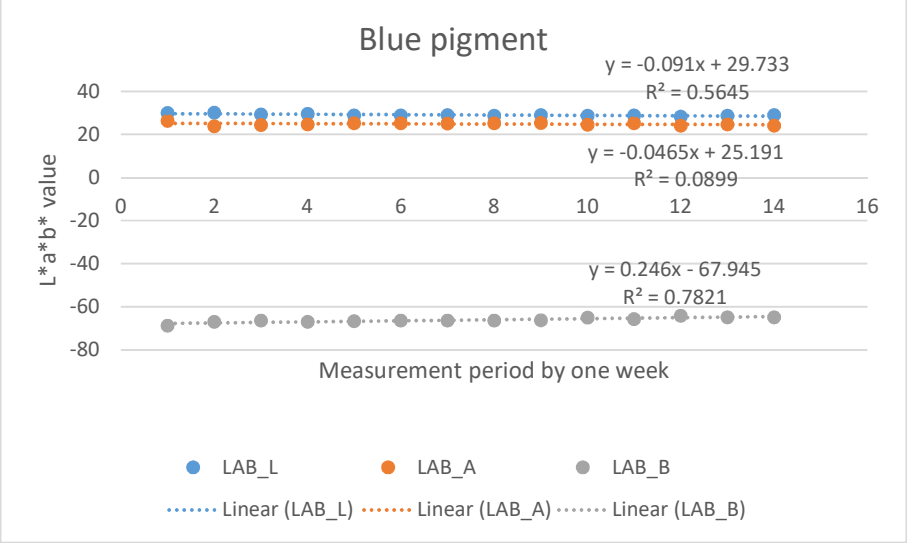
Graphic 1. Regression analysis of Red pigment

In the case of red pigment, the R^2 of L* is 0.5836, and the R^2s of the other two values have a high percentage, indicating that the color fading is quite time consuming.



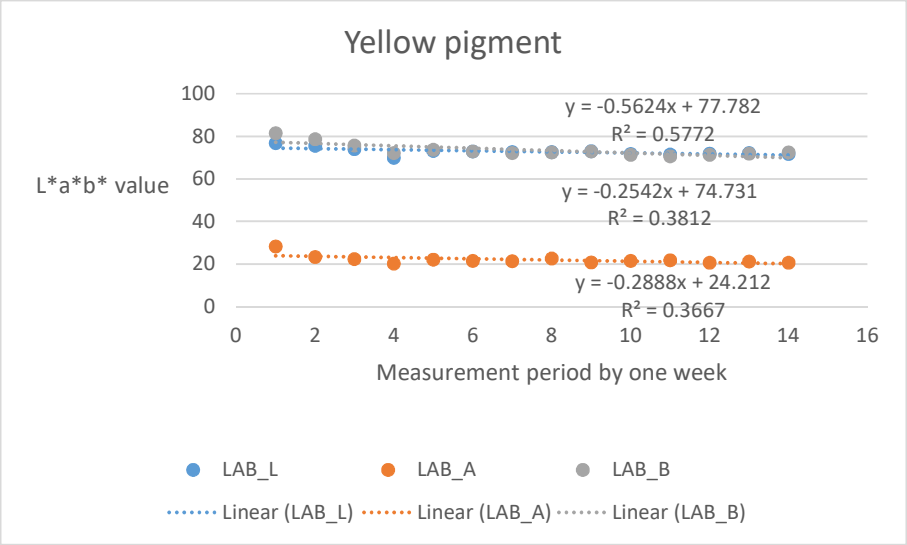
Graphic 2. Regression analysis of green pigment

In the case of green pigment, the R^2 of L* is 0.2639, and the R^2s of the other two values also have a small percentage, indicating a relatively stable color change and less fading.



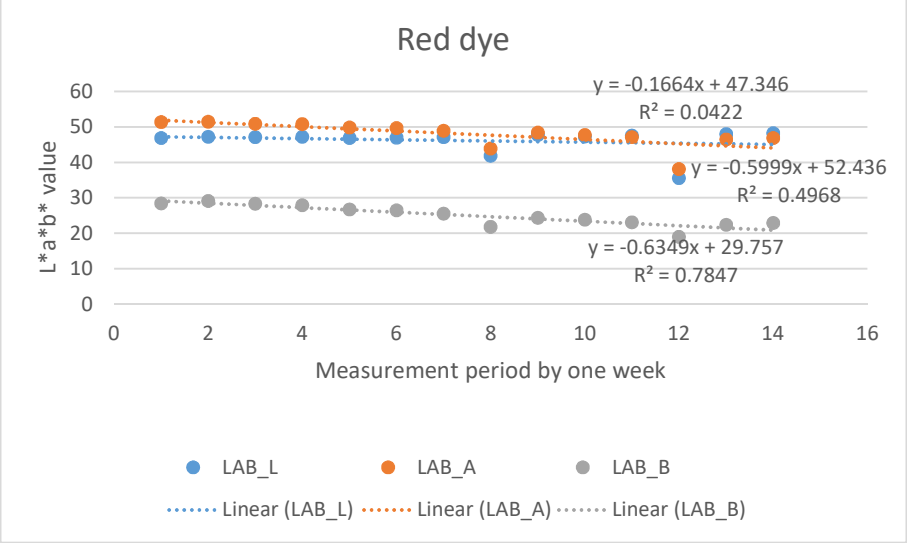
Graphic 1. Regression analysis of blue pigment

In the case of blue pigment, the R2 of L* is 0.5645 and the R2 of the b* values has a high percentage, indicating that the color fading has been significant over time.



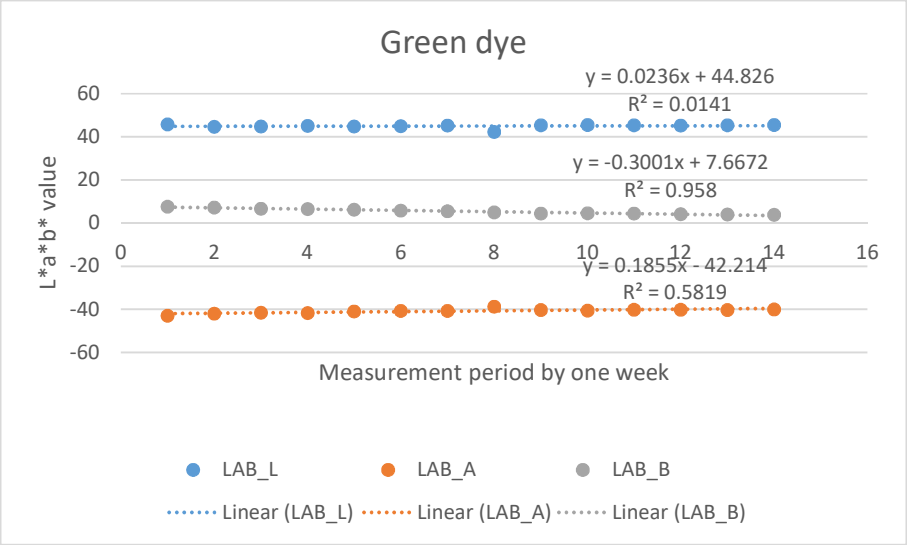
Graphic 4. Regression analysis of yellow pigment

In the case of yellow pigment, the R^2 of L* is 0.5772, so it can be assumed that the color faded.



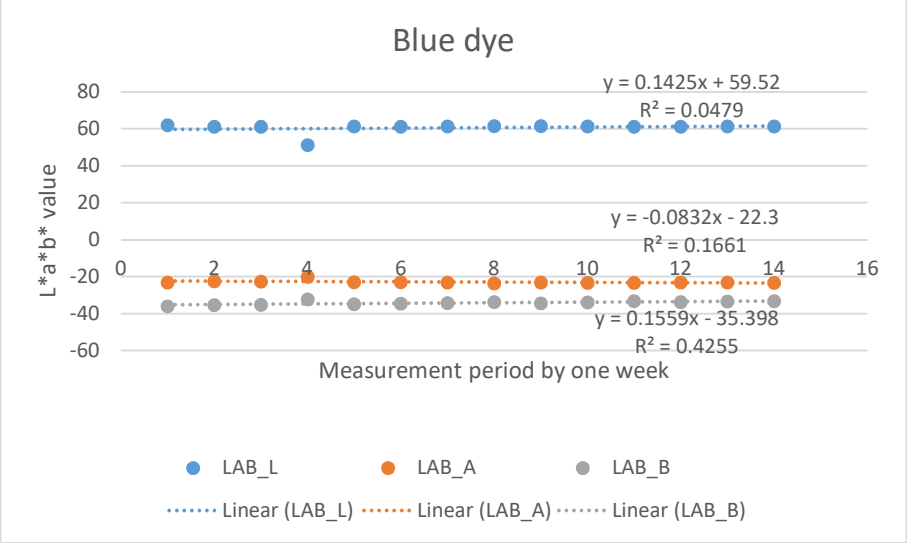
Graphic 5. Regression analysis of Red dye

For red dye, the R^2 of L* is 0.4968, which is a constant level of fading.



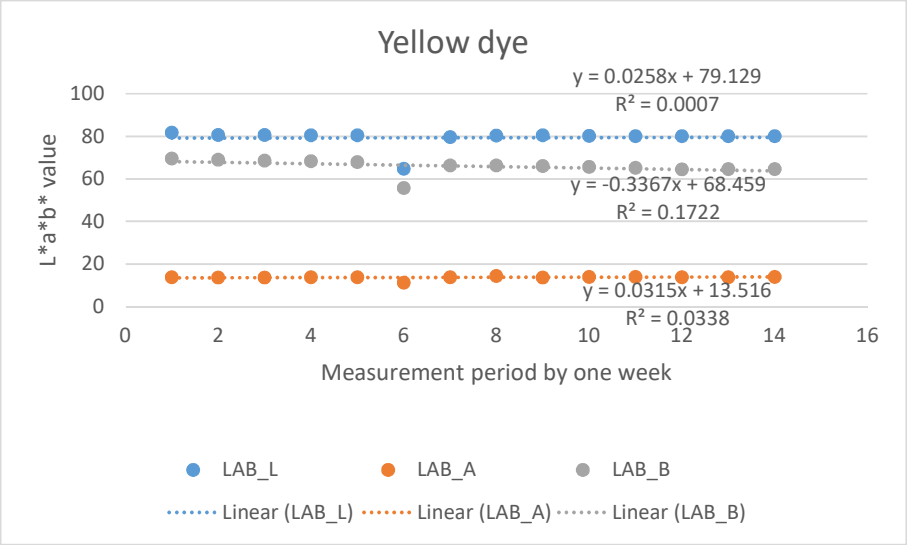
Graphic 6. Regression analysis of green dye

For green dye, the R^2 of L* is 0.0141 or very small, but the R^2s of the other two values have a high percentage, so the fading is small, but the color change is considered to be time-dependent.



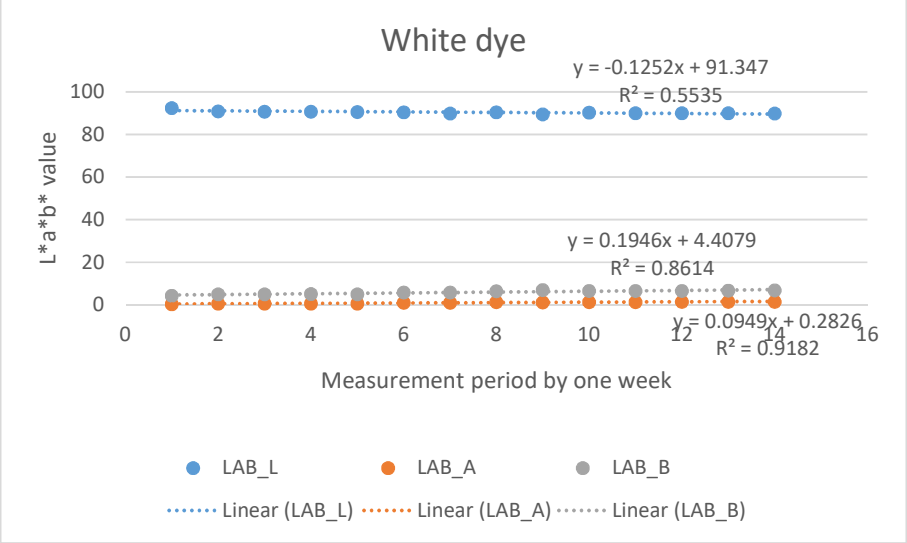
Graphic 7. Regression analysis of blue dye

For blue dye, the R^2 of L* has a very low percentage of 0.0479, and the R^2s of the other two values have a low percentage, so there is almost no color fading or change.



Graphic 8. Regression analysis of yellow dye

As for the yellow dye, it can be concluded that the R^2 of L* has a very low percentage of 0.0007, and the R^2s of the other two values have a low percentage, so the color did not fade or change.



Graphic 9. Regression analysis of white dye

Interestingly, for white dye, the R^2 of L * was 0.5535, so the a* b* values were also high, and the large color change was due to the high air pollution.

Table 2. Measurement data of R^2

№	Colorants	R^2 of L*	R^2 of a*	R^2 of b*	ΔE
1.	Red pigment	0.9195	0.5836	0.8209	21.6706
2.	Green pigment	0.2639	0.3474	0.4832	9.8017
3.	Blue pigment	0.5645	0.0899	0.7821	4.5935
4.	Yellow pigment	0.5772	0.3667	0.3812	12.969
5.	Red dye	0.4968	0.0422	0.7847	7.271
6.	Green dye	0.0141	0.5819	0.958	4.779
7.	Blue dye	0.0479	0.1661	0.4255	2.7605

8.	Yellow dye	0.0007	0.0338	0.1722	5.2863
9.	White dye	0.5535	0.9182	0.8614	7.1172

In order to confirm the values of R^2, we calculated the color difference between the values of the first day of the measurement and the values of the last day of the measurement, ΔE, and found that the red pigment with the highest value of R^2 had the highest color difference of 21.6706. Also, the color difference of the blue dye with the almost lowest value was 2.7605 with the smallest color difference. This R^2 represents the process of fading over time, and the calculation of the color difference indicates how the color changes after such a period, confirming that the two values are consistent.

4. Conclusion

- In this study, long-term and short-term measurements were made weekly for five months to prepare a measurement object for the study of color fading, and regression analysis was used to determine the relationship between color fading and time.
- Processing of the measurement results taking into account this correlation [13] shows that the discoloration and fading of the pigments are more pronounced [11,12]. Most of the dyes were stable, but white colorants changed the most, and when we looked at white with the human eye, we didn't see this color change, but when we measured it with an instrument, there was a lot of change. It is also possible that fading has occurred, regardless of the dyes and pigments, depending on the absorption capacity of the color spectrum. Of course, depending on the chemical composition and elements involved in the production of the color, it depends on environmental factors such as sunlight, wind, temperature and humidity. Most of the pigments have changed a lot, which may be due to a technological error in the preparation of our measurement object.
- From the above results, there is a certain correlation between the R square value and the degree of fading, and we will work in our future study to find the actual statistical meaning of the physical properties of color fading.
- In the future, it is necessary to increase the measurement data and perform more detailed data analysis, and we are aiming to determine the initial color of the object using a machine learning approaches based on regression analysis using the color measurement values. Further research is needed to improve the number and quality of measurement objects and to test them, and combining color research with environmental research and materials science will make the research results more meaningful.

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