Color Muse for Colored Mortar Mixes:
Looking for an Accurate Color Matching Tool in Colored Mortar Production

by

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Abstract

With the rise in demand for decorative concrete, colored concrete started to offer more to the market than its traditional earth-toned color palate. Color matching and blending in concrete and mortar mixes are necessary to provide the consumer with the best variety of product. However, the current tool used in the industry to match color is very expensive. As technology improves, we are able to find cost-effective alternatives for high-priced equipment that still meet required standards of accuracy. This study compares the data generated by $10,000 X-rite spectrophotometer with the $100 Color Muse matching tool. This study involves producing cookie-sized specimens of colored mortar, with varying quantities of pigments, and scanning the sample with both tools in order to generate a color formula specific to each sample. Each sample's formula can then be recreated for use in the production and quality control side of the decorative concrete industry. The goal is to see if the Color Muse can produce a similar formula to that of the X-rite spectrophotometer so that the industry can replace the costly device with the cost-effective alternative without significantly sacrificing quality control of the color selection process.

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Literature Review

Decorative Concrete

The art of decorative concrete adds an aesthetically pleasing element to building with traditional concrete. Often, decorative concrete is associated with "colored concrete." The addition of colors to concrete is one of the easiest ways to get the material to stand out and leave a unique impression (Green is Gorgeous, 2004). In a 2017 survey provided by ConcreteNetwork.com, only 14% of concrete flooring project is done with gray concrete. The other 86% is made up of other colors while 29% of that is a blend of two or more pigments to yield a multi-colored appearance (Concrete Network, 2017). The use of colored concrete started to become popular in the 1920s when the L. M. Scofield Company became the first company to manufacture colored concrete and utilize its products in the construction of houses for Hollywood celebrities such as Charlie Chaplin, Groucho Marx, and Mary Pickford (Nasvik, 1999).

Three common industry techniques used to give concrete color are integral, staining, and color hardeners. In the integral technique, ultra-fine-grained particles, which are resistant to ultra-violet rays and do not fade in light, are mixed homogenously with a cement base and aggregate to produce concrete of specific colors (Tajne & Thakare, 2009). "Advances in computer controls [at the concrete batching plant] help in mixing, creating consistent quality control," says Jamie Farny, a Portland Cement Association representative (Green is Gorgeous, 2004). However, just like with traditional concrete, there needs to be an exact formula that dictates the amount of pigment that must go into the concrete mix to yield the desired results. For example, to produce red-colored concrete, iron oxide is added to white cement. The amount of iron oxide and the particle size of that pigment additive will determine the shade of color that is produced (Che, 2018). Too much iron oxide and the concrete will be a dark red; too little oxide and the concrete will turn pink instead.

Separate from integral pigments, stains and color hardeners are applied to the surface of concrete. Stains, acid based and water based, work by penetrating the surface of concrete. Acid-based stains react with concrete and etch the surface, and water-based stains deposit pigment particles in the pores of the concrete surface. Stains can be diluted to yield different shades (Transforming Concrete Floors, 2018). As of 2017, the global market for decorative concrete is 9.26 billion USD, with projected growth to 12.78 billion by 2022. Of that global market forecast, North America is expected to be the second fastest growing market for decorative concrete in the next five years (Global Decorative Concrete, 2017).

Color Complications in Construction

Besides pigment-to-cement ratio, a crucial factor that affects color variance is the water-to-cement ratio. Batches of colored concrete that have different amounts of water added to them will yield different shades (Sullivan, 2014). Color variance in the finished product is an extremely common issue that can be caused by multiple factors such as weather, moisture in the base, a switch in material suppliers, a change in the mix-design, and even using different tools to finish the surface. With colored concrete, the formwork or mold in which the concrete will be placed needs to be clean, tight to prevent leaking, and made of nonabsorbent material. Oils used to coat the formwork need to not stain the concrete and the formwork needs to be stripped at a consistent time to prevent color variation (Portland Cement Association, 2019). Even after the concrete is placed there is still a risk of a mottled surface if the concrete is not cured properly. Concrete must be cured in a way to prevent damage from efflorescence, a white powder that forms on the surface of concrete from the reaction of leached calcium hydroxide and carbon dioxide in the air. The best recommended form of curing for colored concrete is wet-curing by using either liquid curing compounds or special curing blankets (Concrete Network, 2017). It is common practice for contractors to create a mock-up of the project to serve as a reference for the project and to work with owners and architects to address all of these factors that would influence the finished product's appearance (Decorative Concrete Council, 2014). Because it takes a lot of work to control conditions at the job site, manufacturers of colored cementitious materials do their part to provide a consistent product.

Spectrophotometers and Colorimeters

From the production side of the industry, companies that produce pigments and colored cement products utilize a device called a spectrophotometer. Spectrophotometry is a method of measuring the intensity of light as it passes through objects by seeing how much gets absorbed or transmitted (Vo, 2018). While spectrophotometry is predominantly used in other industries, such as pharmaceuticals and chemical engineering, it is a good method for color matching because color hue is determined by the wavelength that is not absorbed by a material, which a spectrophotometer can measure (Gilbert & Haeberli, 2007). By using spectrophotometers and their software, manufacturers of colored cementitious materials have the ability to generate a database that will show the influence pigment content has on their products. As a result, companies are able to create a custom-blended concrete color mix for their clients by matching the desired color to a color formula from a database. The price of an X-rite brand spectrophotometer ranges from about six thousand to ten thousand USD.

A spectrophotometer is an incredibly accurate device, but there are different color matching tools used in other industries that could potentially be used for the colored cementitious material production process. The Color Muse tool is a reputable color matching implement in the fashion and designing industry priced from sixty to two hundred USD. Therefore, it is much more cost effective compared to the X-rite. Another difference between these two devices is that the Color Muse is a colorimeter, not a spectrophotometer. Colorimeters output data in terms of color characteristics and are made up of colorimetric sensors gauging light from three to four different LEDs (Kirchner et al., 2018). Colorimeters scan the surface color of an object and match it to a cloud-based library of colors (Lange, 2018).

Spectrophotometers tend to be considered the most reliable color measuring instruments because of their ability to "measure light reflected from an object at multiple points across the visible spectrum to obtain an accurate identification of the color" (Bailey, 1998). Even so, it is possible that the Color Muse could be used for the same purpose as a spectrophotometer when it comes to creating custom colored cementitious mix designs.

Thesis Statement

There is reason to think that with the advancements in optical technology, a small color matching tool such as the Color Muse could replace older, more expensive equipment like spectrophotometers in certain material production applications. Color Muse, an inexpensive device that links with a free smartphone application, could be the economical color matching tool to be made widely available to the public to provide close color comparability for decorative concrete production, mixing, and preparation.

This Honors thesis project is a comparative study between the X-rite spectrophotometer and the Color Muse scanner. Colored mortar samples were created using a precise formula and were scanned with a spectrophotometer. The results from the X-rite device were then extracted to form a database, correlating the mix design formula of the test samples with the color formula generated by the X-rite spectrophotometer. Selections of the same colored mortar samples were scanned with the Color Muse, and the Color Muse results were compared to the results from the X-rite.

Methodology

Materials and Equipment

Materials Utilized in Specimen Production:

- Amerimix brand 400-N white base (white cement blend)
- Yipin brand pigment powders (white, black, yellow, red, blue)
- Distilled water

Equipment Utilized in Specimen Production:

- Precisa Gravimetrics brand precision scale (to weigh the pigments)
- Vibra brand scale (to measure base and water)
- Arrow Engineering brand electric mixer (to blend the dry materials)
- Stainless steel spatulas (to hand mix materials, place mix in molds, and strike off surface)
- Two-inch-diameter base disposable coffee cups (to act as a mold and to transfer materials)

Equipment Utilized in Specimen Scanning:

- X-rite Spectrophotometer

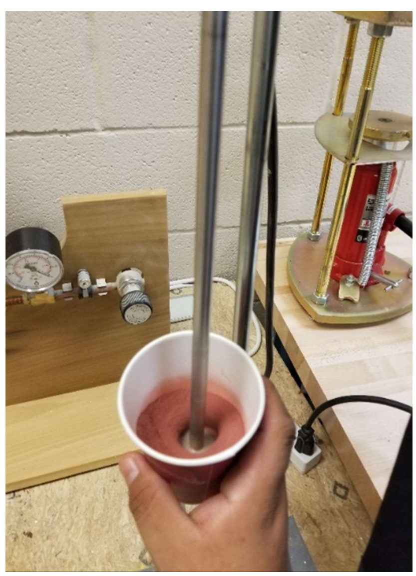
- Color Muse

- iColorQC software for X-rite
- Excel software (to table mix designs and results from scanning)

Operational Methodology Overview

Specimen Production Procedure:

- Measure out ingredients according to the mix design, utilizing a precision scale. (See *Table 1. Production Mixes*)
- Blend the powder ingredients together in a disposable cup.



- Mix with an electric mixer on a high setting for 60 seconds.
- Add required water amount and mix by hand using a stainless-steel spatula.
- Spread the concrete mix on the mold to make two specimens per mix formula.

- Let cure for 30 minutes, then scrape the top layer off to simulate mortar finishing.

The methodology for specimen production and spectrophotometer scanning was not based on set standards by the American Society for Testing and Materials, but rather on industry practice. The company Oldcastle APG has provided MTSU's Concrete Industry Management program the use of the X-rite spectrophotometer and the materials for this study along with instructions on how to form the specimens in order to best replicate conditions in industrial quality-controlled laboratories. To carry out this study with adequate quantitative reliability, approximately 300 specimens were produced and scanned. The procedures listed above are a typical practice for one individual with a low volume of samples to test. In order to meet the required quota, other students were asked to volunteer to assist with specimen production and scanning. As a result, the steps taken in specimen production were changed slightly to maximize and streamline the process while keeping consistency.

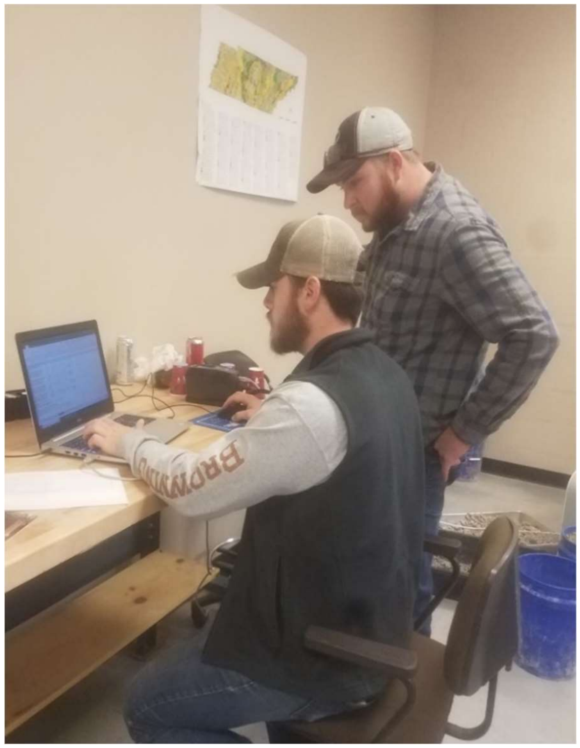
<u>Adjusted Specimen Production Procedure</u>:

- Students were divided into four stations.
- One station measured out the ingredients for six samples. (See *Table 1. Production Mixes*)

- One station operated the mixer and hand mixed the dry ingredients with water.

- One station cast the specimens and scraped the surface after 30 minutes.

- The last station scanned the specimens in accordance with the procedures described below.



Specimen Scanning Procedure:

- Open the software and connect the X-rite spectrophotometer.
- Calibrate the spectrophotometer at the beginning of the day.
- Scan a sample from the mold using the X-rite; set that as the standard.
- Scan the sample twice from the same batch to see if it meets the set standard.
- Repeat the process with the Color Muse.
- Type the results in an Excel file.

Throughout the production process, quality assurance steps were taken to limit the number of external variances that could affect the results in between specimens. The equipment that came in direct contact with the materials, the electronic mixer, and the spatulas was cleaned after every batch to avoid cross contamination of pigments. The Concrete Industry Management Lab Manager, who supervised laboratory aspects of my batch testing, re-created approximately 25% of specimens to verify that the process was consistent. For consistency, the specimens were scanned directly from the mold, at the center of the mold, with the spectrophotometer and the Color Muse.

Scanning Results: X-rite

Each batch/mix yielded two specimen samples. Example: Mix 1 Sample A, Mix 1 Sample B. Each sample was scanned three times by the X-rite Spectrophotometer. The first scan set the sample as the "Standard," and the other two scans are designated as "Trial 1 and Trial 2" (see *Table 2. X-rite Results* and *Table 3. X-rite Results*). Every time the spectrophotometer scanned a sample, it would generate values that correspond to the LAB color model system. The LAB color model system is a three-axial space (Figure 1), where the numerical L, A, and B values correlate to a point in the color space (Rys, 2014). That is the color's formula. Tables 2 and 3 below show the difference in LAB values between each mix. A way to gauge the accuracy of the X-rite was to look at the values it generated between each sample's trials. There should be little to no difference because the device is scanning the same spot in its own enclosed conditions. If there was a huge difference in values, the device would not be reliable.

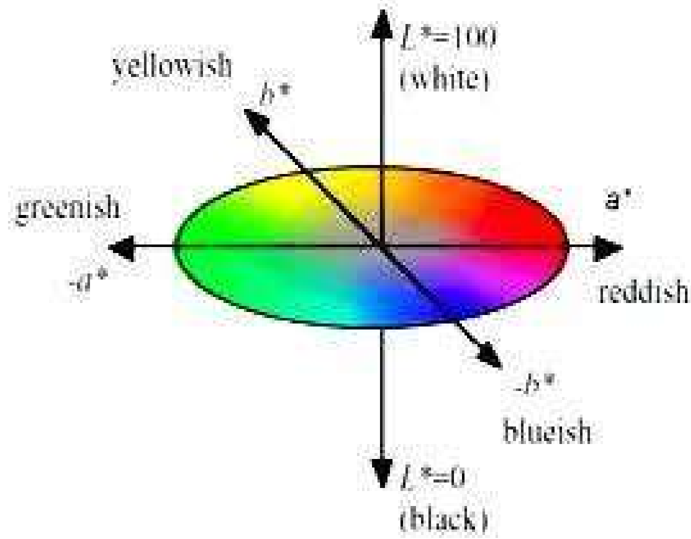


Figure 1. a* negative values indicate green while positive values indicate magenta; and b* negative values indicate blue and positive values indicate yellow (Bora, 2017).

Discussion: Color Muse Results

In the early stages of the project, it was determined that the Color Muse matching tool would be unreliable for measuring color intensity of this ceramic material. *Table 5. Color Muse Results* and *Table 6. Color Muse Results* show there is a difference in notifications between “perceivable color difference” and “significant color difference.” There is significant color difference in the sample that has a rougher texture, a probable cause being the uneven, granular surface of such samples, which cast miniature shadows and hindered the sensitivity of the Color Muse device. Despite many attempts to recalibrate Color Muse, it would report LAB values (white, red, blue; see Figure 1 and Tables 2-6) inconsistently, varying by a large degree. Because all of the specimens had a rough texture, significant color difference was the notification that appeared most often with the Color Muse. Another reason for the uncertainties in the data generated from the Color Muse could be due to the chemical nature of the samples that were produced.

A 2018 study that used spectrophotometers on ceramics discussed the fact that the color perceived and the colorimetric data measured are affected by the temperature variation of the object (Che, 2018). Besides temperature, that same study noted a reason for color variance was due to the physical and chemical compositions of the colorants/pigments (Che, 2018). When water was added to the cementitious material to produce the mortar samples, an exothermic reaction of hydration began. As the cementitious material cures, the reaction stabilizes, and internal heat is lost. With only thirty minutes of curing time allowed, it could be possible that residual heat given off by the reaction in the samples was enough to throw off the sensors in the Color Muse because of its sole dependency of colorimetric data to produce a color formula. The X-rite spectrophotometer was able to give reliable measurements because of its different method for collecting and interpreting data. The Color Muse also relies on external lighting, unlike the spectrophotometer. Even though conditions were kept as consistent as possible, the large difference in results of the same sample shows that the X-rite spectrophotometer's components provide the accuracy that is needed for the quality control side of the decorative concrete industry. Color Muse, conversely, is not consistently reliable in color accuracy for concrete/mortar production applications.

It is important to mention, however, that the Color Muse worked perfectly on different materials. When tried on paint color swatches and fabrics, it yielded consistent values with a degree of variability like that of the X-rite (compare *Table 4. Color Muse*

Results and *Table 3. X-rite Results*). The Color Muse device did not work with precision for the colored mortar specimens of this project. However, just because the Color Muse is not the best tool for quality control in the colored concrete production laboratories, there could still be a use for it in the concrete contracting side of the business. Color Muse does have useful applications.

Potential Applications and Future Research

The results from this study show that the Color Muse was not able to replace the X-rite spectrophotometer in the quality control department of colored cementitious material production. But according to industry professionals like Jim Lange, Vice President of Advanced Color Technologies, Inc., colorimeters were not meant to replace spectrophotometers. “This technology is not designed to replace spectrophotometers and the formulation software platforms available today, but they can certainly provide value and fast returns on a modest investment. Portability and speed, coupled with device accuracy, make this emerging technology worth looking into,” says Lange (2018).

The Color Muse, with its smartphone application, has the capability to suggest colors that would best complement or resemble the color it has scanned. It could be useful in the planning and designing stages of construction where a mockup needs to be created and a special color needs to be ordered. Because there are lots of factors that influence the final look of the concrete or mortar, it could be useful to have this compact and inexpensive device to serve as a guiding point. Also, color in the decorative concrete industry is more than just pigmented cement. Stains and paints can be applied to the top surface of concrete. *Table 5. Color Muse Results* shows that on a smoother surface, there is less of a degree of variability. Color Muse could still be studied at job sites to see if it could be utilized effectively for other purposes.

This study can be recreated and expanded by taking into account factors such as the quality of pigments used in the specimen production; conducting a chemical analysis of the materials used and researching their inherent properties that could influence color perception; making samples that are perfectly smooth and have had more time to cure. Data from colorimeters used in the field would also be valuable to determine their usefulness to people who have to work with colored mortar and concrete, contractors and homeowners alike. The case for portable color matching implements has been made, but the ease of use and the practicality of tools such as Color Muse needs to be further investigated.

Conclusions

This research project focused on comparing the data generated by the X-rite spectrophotometer to the data generated by the Color Muse matching tool to determine if the same accuracy and precision could be measured with a low cost, convenient device being the Color Muse tool. The X-rite spectrophotometer is by far superior in terms of precision and accuracy when scanning colored cementitious samples due to internal equipment technology. The Color Muse can be compared more closely with the mobile phone technology which can take surface scans/images of physical objects. Color Muse does work similarly to the X-Rite by scanning a sample, setting it as the reference, and generating a numeric color formula for that sample. The Color Muse then scans a different sample and compares the results to the reference sample (as in Tables 4-6). How much the color formula varies is a measure of the precision of the Color Muse, or its lack of precision, depending on the material of the sample.

The difference in perceivable color shade is a measure of how accurate a device is when based on a control shade. When the X-rite scanned a colored mortar sample, the color formula values and the color shades matched near perfectly, every time. X-rite was both consistently precise and accurate. When the Color Muse scanned a colored mortar sample, the color formula values varied significantly, but the color shade appeared similar. Thus, the Color Muse is not as precise as the spectrophotometer, but it is somewhat accurate in terms of color perception.

Individuals perceive color quite differently, and in terms of consumers' choosing color, Color Muse may provide a useful range of color variability. A contractor may provide a sample of colored concrete and then give a range of shades closely matching the colored sample so that the owner is aware of variability in color applications. It is possible that the Color Muse would give more precise results if it is used on smooth concrete surfaces instead of on the rough-surfaced mortar specimens of this study. When the Color Muse is used on flat, smooth surfaces such as magazines and paint swatches, the device's precision and accuracy increase dramatically, nearing spectrophotometer quality. In most indoor decorative concrete applications, the finished surface is not as rough as stucco and grout. When dying interior concrete, for example, small particles of dye penetrate the concrete, filling in the voids. Voids present in this Honors study's roughened specimens contributed to the varying results of the Color Muse.

It is extremely difficult to control all of the factors that affect color in concrete placement. Concrete contractors and their clients may need to establish a reasonable tolerance in color shade range. The Color Muse's ability to determine significant perceivable color difference could be a tool to help compare the finished concrete to the agreed-upon color choice of the mock-up the contractor gave the client at the beginning of a project. Also, if the Color Muse is to be tested in the field in the future, it is important to remember that lighting can significantly affect the results generated by the Color Muse. This Honors study was conducted indoors and has not been tested to account for the variability of outdoor lighting and shading. In sum, the Color Muse may be expected to perform within industry tolerances for color variation and therefore have some consumer utility.

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Appendix:

Tables 1-6

Table 1. Production Mixes

Sample Preparation Guide - White/Black/Resin Mixes

		White Base		*White(Tio2)*		*Black*		
grams	g	Amount	Actual	Amount	Actual	Amount	Actual	Total
Mix #	1	100.000	100.000	-------	-------	-------	-------	100.000
Mix #	2	100.000	100.020	2.000	2.002	-------	-------	102.000
Mix #	3	100.000	100.050	1.605	1.607	-------	-------	101.605
Mix #	4	100.000	100.050	1.005	1.006	-------	-------	101.005
Mix #	5	100.000	100.040	0.005	0.006	-------	-------	100.005
Mix #	6	100.000	100.000	-------	-------	2.000	1.998	102.000
Mix #	7	100.000	100.030	-------	-------	1.605	1.605	101.605
Mix #	8	100.000	100.020	-------	-------	1.005	1.006	101.005
Mix #	9	100.000	100.000	-------	-------	0.005	0.007	100.005
Mix #	10	100.000	100.030	0.200	0.201	1.800	1.803	102.000
Mix #	11	100.000	100.030	1.800	1.800	0.200	0.203	102.000
Mix #	12	100.000	100.010	1.000	1.000	1.000	1.001	102.000

This table shows the mix design used in the production of the first twelve batches. The highlighted sections show how many grams of materials went into batch production. Example: The batch 10 (Mix # 10) recipe required 100.000 grams of white base, 0.200 grams of white pigment, and 1.800 grams of black pigment. However, the actual amounts of base/pigment that went batch 10 were 100.030 grams of white base, 0.201 grams of white pigment, and 0.203 grams of black pigment.

Table 2. X-rite Results

Name	L*	a*	b*	C*	h°		
Step 1 Mix 1 Sample A	72.66	1.36	6.97	7.1	78.93		
Step 1 Mix 1 Sample A Trial 1	-0.06 D	0.08 R	0.23 Y	0.24 B	-0.03 R	0.23	Passed
Step 1 Mix 1 Sample A Trial 2	0.15 L	0.05 R	0.29 Y	0.30 B	0.01	0.29	Passed
Step 1 Mix 1 Sample B Standard	70.26	1.61	7.98	8.14	78.62		
Step 1 Mix 1 Sample B Trial 1	1.16 L	0.04 R	0.11 Y	0.12 B	-0.01	0.46	Passed
Step 1 Mix 1 Sample B Trial 2	1.68 L	0.03 R	0.20 Y	0.20 B	0.01	0.68	Passed
Step 1 Mix 2 Sample A Standard	71.23	0.93	5.61	5.69	80.6		
Step 1 Mix 2 Sample A Trial 1	0.37 L	0	0.04 Y	0.04 B	0	0.15	Passed
Step 1 Mix 2 Sample A Trial 2	0.54 L	0.02	0.03 Y	0.04 B	-0.01	0.21	Passed
Step 1 Mix 2 Sample B Standard	75.82	0.81	5.33	5.4	81.32		
Step 1 Mix 2 Sample B Trial 1	0.25 L	0	0.02 Y	0.02 B	0.01	0.1	Passed
Step 1 Mix 2 Sample B Trial 2	0.35 L	0	0.03 Y	0.03 B	0	0.14	Passed
Step 1 Mix 3 Sample A Standard	74.33	1.01	5.93	6.02	80.35		
Step 1 Mix 3 Sample A Trial 1	0.08 L	0.01	0.01	0.01	0	0.04	Passed
Step 1 Mix 3 Sample A Trial 2	0.10 L	0.01	0.01	0.01	-0.01	0.04	Passed
Step 1 Mix 3 Sample B Standard	73.05	1.05	6.14	6.23	80.34		
Step 1 Mix 3 Sample B Trial 1	0.10 L	0	0.01	0.01	0	0.04	Passed
Step 1 Mix 3 Sample B Trial 2	0.06 L	0	0	0	0	0.03	Passed
Step 1 Mix 4 Sample A Standard	70.39	1.3	6.73	6.85	79.08		
Step 1 Mix 4 Sample A Trial 1	0.07 L	0	0.01	0.01	0	0.03	Passed
Step 1 Mix 4 Sample A Trial 2	0.09 L	0	0.01	0.01	0	0.04	Passed
Step 1 Mix 4 Sample B Standard	72.86	1.06	5.99	6.08	79.98		
Step 1 Mix 4 Sample B Trial 1	0.06 L	-0.01	0.01	0	0.01	0.02	Passed
Step 1 Mix 4 Sample B Trial 1	0.08 L	0	0.01	0.01	0	0.03	Passed
Step 1 Mix 5 Sample A Standard	70.13	1.41	7.07	7.21	78.69		
Step 1 Mix 5 Sample A Trial 1	0.12 L	0	0.01	0.01	0	0.05	Passed
Step 1 Mix 5 Sample A Trial 2	0.15 L	0	0.02	0.02	0	0.06	Passed
Step 1 Mix 5 Sample B Standard	67.64	1.36	6.98	7.11	78.98		
Step 1 Mix 5 Sample B Trial 1	0.03 L	0	0.01	0.01	0	0.01	Passed
Step 1 Mix 5 Sample B Trial 1	0.04 L	0	0.01	0.01	0	0.02	Passed
Step 1 Mix 6 Sample A Standard	25.34	1.02	-0.17	1.04	350.78		
Step 1 Mix 6 Sample A Trial 1	0.02 L	0	0.01	-0.01	0	0.02	Passed
Step 1 Mix 6 Sample A Trial 2	0.01	0	0	0	0	0.01	Passed
Step 1 Mix 6 Sample B Standard	27.19	1.01	-0.11	1.02	353.63		
Step 1 Mix 6 Sample B Trial 1	0.01	0.02	-0.02 B	0.02	-0.02 B	0.04	Passed
Step 1 Mix 6 Sample B Trial 2	0.05 L	0	-0.01	0.01	-0.01	0.04	Passed

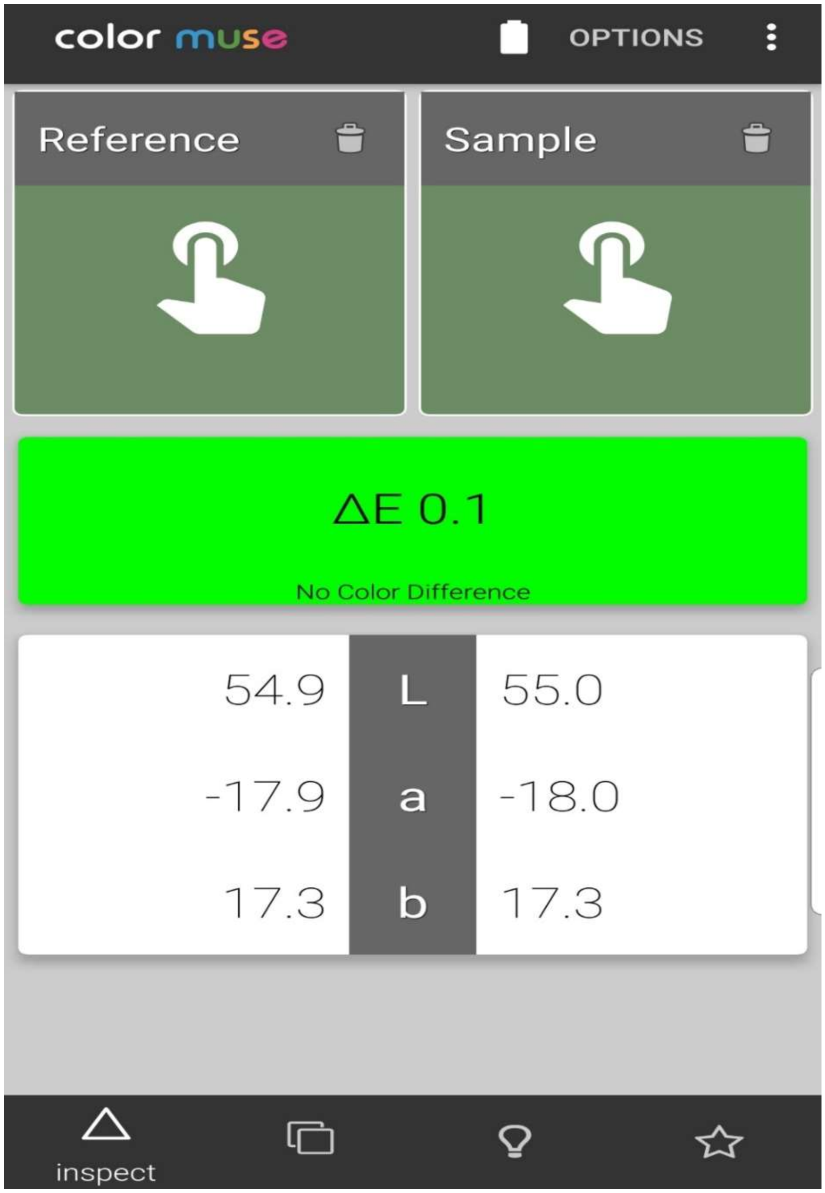
This table shows the data extracted from the X-rite Spectrophotometer Color iQC software for the first six batches. Each mix, see Production Table 1, yielded 2 specimen samples. Each sample was independently set as a standard and scanned in order to generate an L.a.b color formula. The data show that there is little to no difference in LAB values between the A samples and its two trials, and the B samples and its two trials.

Table 3. X-rite Results

Step 1 Mix 23 sample A Standard	36.99	25.4	17.03	30.58	33.84		
Step 1 Mix 23 sample A Trial 1	0.01	0.01	-0.01	0	-0.01	0.01	Passed
Step 1 Mix 23 sample A Trial 1	-0.23 D	-0.06 G	-0.13 B	-0.12 D	-0.07 R	0.16	Passed
Step 1 Mix 23 sample B Standard	37.51	25.29	16.74	30.33	33.5		
Step 1 Mix 23 sample B Trial 1	0.03 L	0.01	0.01	0.01	0	0.02	Passed
Step 1 Mix 23 sample B Trial 2	0.36 L	0.10 R	0.02 Y	0.10 B	-0.04 R	0.2	Passed
Step 1 Mix 24 sample A Standard	39.13	25.07	16.63	30.09	33.55		
Step 1 Mix 24 sample A Trial 1	0.01	0	0	0	0	0	Passed
Step 1 Mix 24 sample A Trial 2	-0.29 D	-0.11 G	-0.07 B	-0.13 D	0.01	0.17	Passed
Step 1 Mix 24 sample B Standard	37.5	24.57	16.28	29.47	33.53		
Step 1 Mix 24 sample B Trial 1	0.02 L	0.02	0	0.02	-0.01	0.02	Passed
Step 1 Mix 24 sample B Trial 2	0.01	0	0	0	0	0.01	Passed
Step 1 Mix 25 sample A Standard	44.92	22.68	14.12	26.72	31.9		
Step 1 Mix 25 sample A Trial 1	0.04 L	0.01	0.01	0.01	0	0.02	Passed
Step 1 Mix 25 sample A Trial 2	0.05 L	0.01	0.01	0.02	0.01	0.03	Passed
Step 1 Mix 25 sample B Standard	45.12	23.12	14.52	27.3	32.13		
Step 1 Mix 25 sample B Trial 1	0.21 L	0.08 R	0.06 Y	0.10 B	0	0.11	Passed
Step 1 Mix 25 sample B Trial 2	0.20 L	0.07 R	0.05 Y	0.09 B	0	0.11	Passed
Step 1 Mix 26 sample A Standard	63.57	5.58	10.2	11.63	61.32		
Step 1 Mix 26 sample A Trial 1	0.13 L	0.01	0.03 Y	0.03 B	0	0.06	Passed
Step 1 Mix 26 sample A Trial 2	0.19 L	0.01	0.04 Y	0.04 B	0.01	0.08	Passed
Step 1 Mix 26 sample B Standard	65.54	5.73	10.53	11.99	61.45		
Step 1 Mix 26 sample B Trial 1	0.08 L	0.01	0.01	0.01	-0.01	0.03	Passed
Step 1 Mix 26 sample B Trial 2	0.13 L	0.01	0.02	0.02	0	0.05	Passed
Step 1 Mix 27 sample A Standard	55.66	16.28	9.72	18.96	30.84		
Step 1 Mix 27 sample A Trial 1	0.02	0	-0.01	0	0	0.01	Passed
Step 1 Mix 27 sample A Trial 2	0.03 L	0.01	-0.01	0	-0.01	0.02	Passed
Step 1 Mix 27 sample B Standard	56.72	15.87	9.4	18.44	30.63		
Step 1 Mix 27 sample B Trial 1	0.01	0	0.01	0	0.01	0.01	Passed
Step 1 Mix 27 sample B Trial 2	0.03 L	0	0	0	0	0.01	Passed

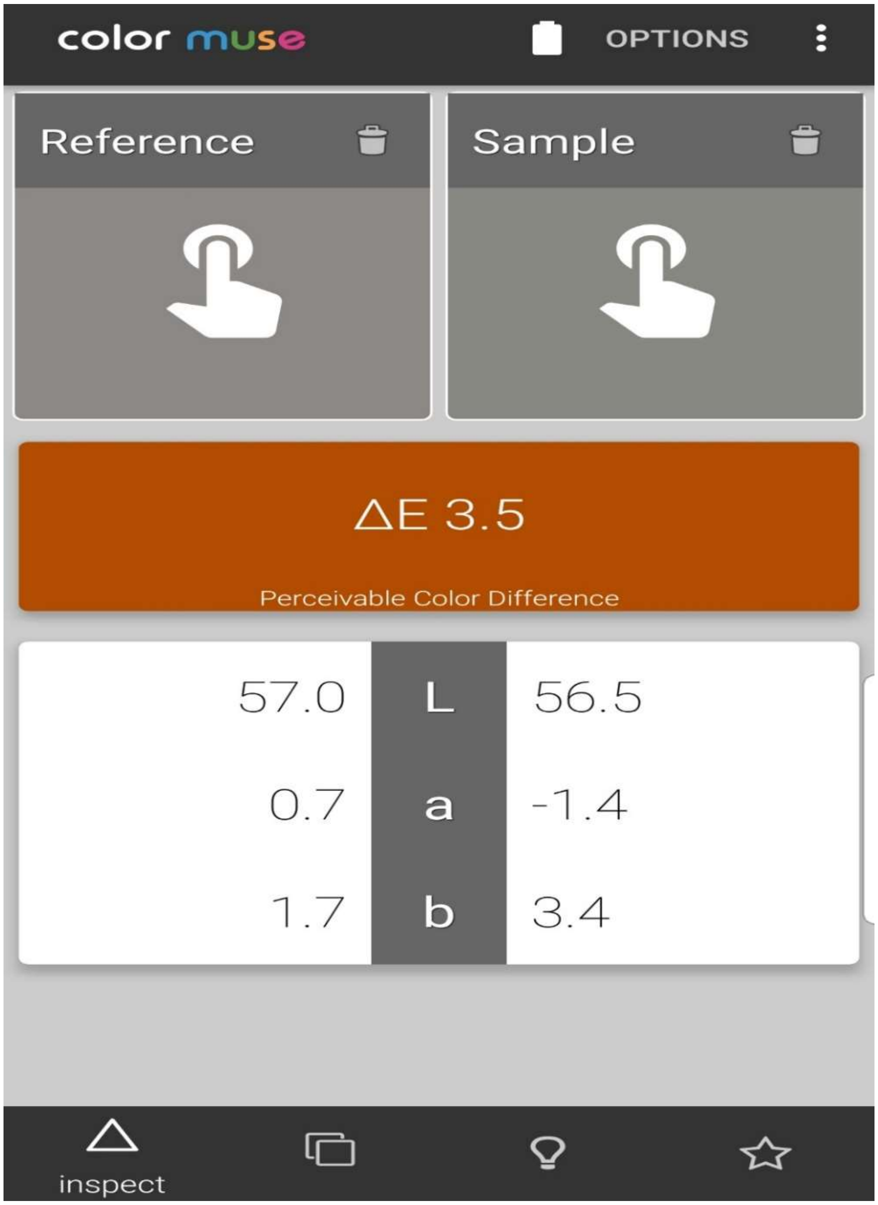
This table shows the data extracted from the X-rite Spectrophotometer Color iQC software for the batch 23 through 27. Even when there is a bigger difference between the A samples and B samples, there is minimal perceivable color difference. Example: Mix 23 A has an L value of 36.99 and Mix 23 B has an L value of 37.51: 0.52 difference. See *Table 5. Color Muse Results* for a perceivable color difference according to the color formula.

Table 4. Color Muse Results



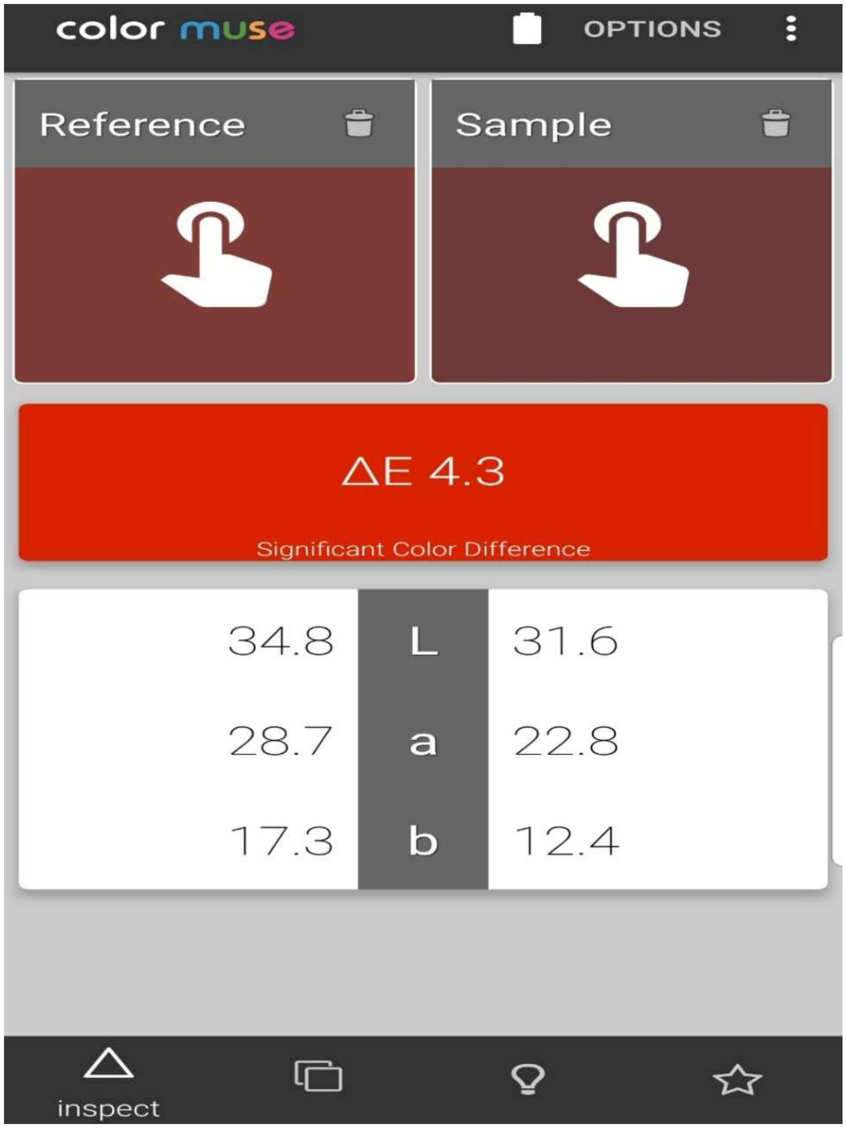
This table shows the data extracted from the Color Muse matching tool. In this image, the Color Muse is being used on a smooth section of a paint catalogue. It was scanned twice in the same spot and the LAB values outputted were almost exact. The device works accurately on this type of paper material. The variability is almost the same as the X-rite in this case.

Table 5. Color Muse Results



This table shows the data extracted from the Color Muse utilized on a semi-smooth concrete surface. Even though the two scans were taken from the same spot, there is a perceivable color difference. This notification appeared occasionally.

Table 6. Color Muse Results



This data sample was taken from Mix 23 using the Color Muse. Specimen 23 A was scanned twice at the same spot and there was a significant color difference. All specimens scanned had a rough and granular surface. Almost every other scan yielded a significant color difference using the Color Muse. The results did not vary to the same degree with the X-rite. It is safe to assume that the roughened texture of the mortar samples accounts for the degree of variability when compared to *Table 5. Color Muse Results.*