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Performance and Durability of Paints for the Conservation of Historic Façades

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Abstract: This paper analyzes the performance of various types of paints available in the Brazilian market, including PVA, matte acrylic, silicate, and lime paints within the context of their applicability to the conservation of historic building facades. Considering distinct suppliers and application methods, this study highlights the importance of tailoring paint selection to the preservation requirements of historic edifices, taking into account local preservation norms and the material characteristics of the buildings' original construction. The paints were evaluated based on water vapor permeability, washability, and adhesion. Furthermore, the paints' color variation with exposure to accelerated artificial aging was assessed. For testing purposes, specimens produced from cellular concrete slabs were used as substrates, which were coated with the paints under study. Based on the results, it was observed that, regarding the diffusion of water vapor, the silicate and lime paints presented the highest permeability values, and the acrylic and PVA paints had the lowest. Concerning washability, the silicate and lime paints showed the greatest wear. The adhesion tests revealed that, except for lime paint, detachment often occurred at the substrate. As for the accelerated aging test, lime paint exhibited the most significant color variation, losing its pigmentation considerably over time. With the results of this research and considering the main preservation requirements of historic coatings, silicate-based paints may be considered the most suitable.

Keywords: paint; performance; durability; accelerated aging; historic facades

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1. Introduction

The use of paint as both an exterior and interior finishing layer on buildings is a common practice in Brazil. For many years, paint has been primarily applied for its aesthetic appeal, except for whitewashes, which have served as a protective element for the plaster. It is currently widely recognized that paint coatings play a crucial role in safeguarding buildings against numerous factors that affect their deterioration [1–4].

Therefore, paints have a dual function, addressing aesthetic concerns and safeguarding the substrates to which they are applied. Consequently, the application of paints and the assessment of their performance must consider their compatibility with the substrate's characteristics. This aims to prevent corrosion, enhance resistance to chemical abrasion, and mitigate the growth of fungi, among other factors [5–7].

Brazil is one of the world's five largest paint markets, as reported by ABRAFATI (Brazilian Association of Paint Manufacturers), manufacturing products with advanced technology and high performance. The real estate paint segment stands out, constituting over 80% of the total volume manufactured [8].

Within the context of architectural maintenance and conservation, paints serve multifaceted roles that transcend mere aesthetics. As a protective measure, they establish a barrier between the support/substrate and the external environment, ensuring satisfactory performance against water and potential solvents that could compromise the substrate's integrity. Furthermore, the waterproofing capability of paints is crucial for filling voids on highly porous surfaces, thus bolstering the structure's resistance to water's detrimental effects. Additionally, paints significantly contribute to hygiene and health by safeguarding surfaces against the proliferation of microorganisms and bacteria, highlighting their indispensable role in the comprehensive preservation of architectural heritage [1].

PVA latex, acrylic, silicate, and lime-based paints are among the various types of paints. In general, paints are composed of essential components, including a fixed medium (binder/resin), a volatile medium (solvent/diluent), pigments, fillers, and additives [9]. The binder or resin plays a crucial role in binding the particles of pigments, fillers, and/or solid additives, imparting properties such as hardness, strength, flexibility, and adhesion [6,10]. Solvents facilitate the paint's manufacturing and application processes, promoting contact with the substrate and enhancing adhesion. On the other hand, pigments consist of solid particles dispersed within the paint, providing characteristics such as color, opacity, durability, and mechanical strength [11–14]. Fillers can be added to adjust the formulation's viscosity, modify the facades' volume and technical properties, and influence cost by optimizing the qualities of more expensive pigments. Lastly, additives used in small amounts can enhance or alter the final coating or the material's properties during production, storage, transportation, or application [5,15].

PVA latex paints, based on polyvinyl acetate, exhibit lower adhesion strength, durability, and resistance to water and alkalinity when compared to acrylic paints; thus, they are more commonly used in the interiors of buildings [16]. On the other hand, acrylic paints are among the most widely used in construction. They are produced from pure acrylic, styrene-acrylic, and vinyl ester copolymers and polymers, enabling high durability, strong substrate adhesion, ease of application, and quick drying. Additionally, they resist the penetration of liquid water, vapor transfer, ultraviolet (UV) radiation, and alkalinity (Morais, 2019 [17]). When comparing PVA and acrylic paints, the pigment volume content (PVC), representing the volume of pigment in the dry paint film relative to the total volume of the dry film [18], may be responsible for variations in properties. Higher PVC results in increased permeability and reduces gloss in the paint film [18].

Silicate paints consist of an inorganic binder, typically potassium silicate, combined with an organic binder (polymer or acrylic emulsion). They also incorporate fillers, inorganic pigments, and water, resulting in mineral-based coatings. These paints feature a limited color spectrum because of the use of mineral pigments. Their highly alkaline nature is incompatible with organic pigments, similar to the behavior of lime-based paints. The drying process for silicate paints is intricate, and due to their specific characteristics, they are not recommended for application on organic substrates but are better suited for use on inorganic plaster surfaces. Silicate paints exhibit high vapor permeability and resistance to fungal growth due to their porous inorganic structure and mineral composition, respectively [19,20].

Lime paint can be produced by adding pigments to an aqueous solution of calcium hydroxide, which assumes the role of a binder, following the evaporation of water and the carbonation reaction with atmospheric carbon dioxide. During this process, the pigment particles become embedded within the crystalline matrix of the calcium carbonate formed, resulting in a continuous paint layer. Lime painting was one of the most popularly widespread used in the past [21]. Today, there are still preserved examples in historic city centers and rural areas where this material was applied, which are under assessment for historical documentation and potential restoration efforts [22]. However, the preservation of these sites is threatened as many important historic buildings and districts are being destroyed, while others simply die of desertion and decay, and others are still transformed into slums [4].

As paint is the outermost layer of the facade walls, it is directly exposed to degradation agents over time, requiring maintenance, potential corrections, and even repainting [23,24]. Within the context of historic building facades, painting is closely related to the visual aesthetics and historical significance of the structure. Which represent the built and cultural heritage of societies and whose preservation is essential [25]. Therefore, an in-depth understanding of the technical criteria for historic preservation becomes indispensable, which entails using traditional construction techniques and appropriate materials [20,26]. For instance, when considering the facades of older buildings, it is crucial to select paints that offer adequate vapor permeability because the rendering mortars may exhibit significant porosity, and, thus, reducing the vapor permeability in the finishing layer could result in the accumulation of liquid water and subsequent deterioration [3].

Knowledge of paint properties such as vapor permeability, washability, adhesion, and color stability under conditions of accelerated aging enables conservation professionals to make informed decisions about the most appropriate materials for specific conservation projects. For instance, the ability to choose paints with high vapor permeability is crucial for maintaining the breathability of historic walls, preventing moisture accumulation that could lead to structural damage or the growth of harmful biological organisms [1,3,23–25].

Considering the significance of assessing appropriate characteristics and ensuring compatibility when undertaking interventions on historic buildings, it is imperative to enhance the understanding of potentially employed materials [27–30]. The primary objective of this study was to examine the performance in terms of water vapor permeability, washability, adhesion, and durability, including color stability during exposure to accelerated aging, of various paints and application techniques. Seven different paint configurations were investigated, including PVA latex, matte acrylic, silicate, and lime-based paints readily available in the Brazilian market. In the case of acrylic paints, the focus was on matte finishing due to the probable higher PVC than satin acrylic paints [18]. This detailed approach aims to significantly contribute to the practices of maintenance and conservation of historic facades, addressing different suppliers and application methods that respect and preserve the heritage value of buildings.

2. Materials and Methods

2.1. Materials

Seven distinct paint formulations were employed, each possessing unique properties, to conduct the analyses. Dilution ratios and application methods for all paints were meticulously adhered to according to the suppliers' specifications, as detailed in Table 1. This included the PVA paint, which was diluted by 20% volume with water and applied using a wool roller in two layers, and similarly treated matte acrylic yellow paints identified as MA_1 and MA_2. Contrarily, the silicate-based paints, specifically the yellow (YS and YS_3) and brown silicate (BS) variants, were applied undiluted, also using a wool roller. The lime paint, uniquely mixed with liquid yellow dye, was applied with a brush in a single layer without dilution, employing a cross-coat technique recommended by the manufacturer to ensure maximum adhesion and uniformity. This comprehensive approach, strictly following the manufacturers' guidelines, aimed to assess the performance of these paints under consistent and controlled conditions.

Table 1. Paint formulations.

Paint	Dilution	Applicator	Number of Coats
PVA	20%	Wool roll	2
Yellow matte acrylic (MA_1)	20%	Wool roll	2
Yellow matte acrylic 2 (MA_2)	20%	Wool roll	2
2-Layer yellow silicate (YS)	-	Wool roll	2
3-Layer yellow silicate (YS_3)	-	Wool roll	3
2-Layer brown silicate (BS)	-	Wool roll	2
Lime + yellow dye (L)	-	Paintbrush	1

To color the lime paint, a yellow liquid dye was added (15 drops per 50 mL of paint), and, additionally, the paint was applied with a cross coat, as recommended by the manufacturer. The other paints were applied in 2 or 3 individual coats and were diluted with tap water.

The paints used in this study were intentionally selected for their widespread application in the painting and conservation of historic buildings in Brazil. These paint types not only represent the most commonly utilized in the field of heritage conservation but were also part of a curated group chosen for a real-case study aimed at determining the most suitable paint for the restoration of a historic building. This selection process was informed by a comprehensive assessment of their compatibility with the preservation requirements and the specific characteristics of historic facades, underscoring their relevance to both practical conservation efforts and the broader objectives of cultural heritage preservation. The test specimens were produced using cellular concrete slabs as a substrate, cut to the required size for the tests. The aim was to simulate a porous structure as a substrate for applying the paints, attempting to resemble the characteristics of a historical mortar.

2.2. Methods

The performance of the paints was assessed using water vapor permeability, washability, and substrate adhesion tests. Durability was assessed by exposing test specimens to accelerated aging with photographic monitoring and color variation.

An Analysis of Variance (ANOVA) was conducted with a 95% confidence interval for the water vapor permeability tests and accelerated artificial aging with color monitoring. Additionally, the Fisher LSD method was used for multiple comparisons between means.

2.2.1. Water Vapor Permeability

The water vapor permeability test followed the guidelines of the ASTM E96/E96M standard [31] using the desiccant method. A total of 32 specimens 10 cm in diameter and 2.5 cm thick were tested, 4 specimens for each paint formulation and 4 for the unpainted substrate. After painting, the specimens had their sides sealed with rubberized paint and were placed in chambers with a relative humidity of 50%.

By regulatory requirements, the specimens were positioned on polyvinyl chloride (PVC) supports containing calcium chloride ($CaCl_2$) desiccant to initiate the test. The relative humidity in the chambers was maintained at 50 ± 5% using a saline solution of magnesium nitrate ($Mg(NO_3)_2$), and the temperature was kept at 21 ± 1 °C. Figure 1 illustrates the test preparation and execution.

Figure 1. (**a**) Painting the substrates; (**b**) specimens with sealed sides arranged in the glass chamber; (**c**) PVC support with calcium chloride desiccant ($CaCl_2$); (**d**) sealing the sides of the support with silicone; (**e**) supports with specimens in the chamber with relative humidity of 50 ± 5%.

2.2.2. Washability

A piece of humid surgical gauze was rubbed over the specimens' surface to evaluate the paints' washability, and the number of rubs made without the finishing layer wearing off was recorded, following the method presented in Polito [32]. A total of 3 specimens were assessed for each paint formulation, and paints were considered of good quality if they withstood 200 rubs or more.

2.2.3. Adhesion of Paints to the Substrate

The adhesion of the paints to the substrate was evaluated following the guidelines of the ASTM D4541 standard [33] for conducting the pull-off adhesion test using a DeFelsko PosiTest AT-A tester, which assesses the adhesion strength of a coating system. A total of 3 studs were affixed, with a two-component epoxy and cyanoacrylate glue being utilized, to the previously cleaned surface of each specimen (Figure 2). This adhesive does not affect the coating properties, penetrate through the coating, or degrade the coating. This approach aligns with the recommendations set forth in ASTM D4541 [33]. Subsequently, the test apparatus was connected to the aligned loading device to apply perpendicular stress to the test surface with a gradual and uniform increase of 1.0 MPa/s, and the behavior was observed until the loading device detached.

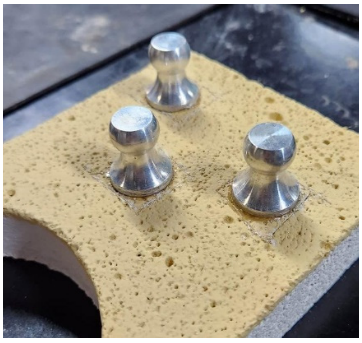

Figure 2. Specimen submitted to the adhesion test D4541 [33].

The properties of both the glue and the substrate play critical roles in influencing the type of failure and the strength of the bond in adhesion tests, such as those described by ASTM D4541 [33] for evaluating the pull-off strength of coatings. The chemical composition of the adhesive determines its curing mechanism, bond strength, flexibility, and resistance to environmental factors. An adhesive with high bond strength and appropriate flexibility for the substrate material can distribute stresses more evenly, potentially reducing the likelihood of adhesive failure (where the bond between the adhesive and the substrate or coating fails) and cohesive failure (where the material itself fails internally). As for the substrate properties, the porosity, surface roughness, and chemical composition affect how the adhesive bonds to it. A porous substrate may allow for better mechanical interlocking, improving adhesion strength, but it might also absorb part of the adhesive, reducing its effectiveness. Surface roughness can increase the effective bonding area but requires an adhesive capable of adequately wetting the surface. Additionally, the chemical compatibility between the substrate and the adhesive is crucial to prevent degradation of the bond over time [33].

2.2.4. Exposure to Accelerated Artificial Aging and Color Monitoring

The specimens with different paint formulations were subjected to accelerated aging following Cycle 1 of the ASTM D6695 standard [34], which consists of 102 min of continuous exposure to light at a relative humidity of 50 ± 5% and a black panel temperature of 63 ± 2 °C, followed by 18 min of precipitation using a deionized water spray. Thus, each cycle lasted 2 h. The weathering chamber was the Suntest XXL+ model from Atlas Material Testing Technology, equipped with 3 1700 W xenon lamps. The typical irradiance applied during the test was 0.35 ± 0.02 W/(m^2-nm) at 340 nm [33].

Throughout the aging process, the properties of the specimens were continuously monitored using photographic records and colorimetric analysis, which involved chromatic coordinates obtained with a portable Konica Minolta CM-2500D spectrophotometer. A specialized camera with controlled lighting conditions was used to capture the photographs, ensuring uniformity. Chromatic coordinates were acquired for each specimen at 5 fixed points, fixed with a paper gauge. The color variation (ΔE) was calculated following Equation (1) [35].

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

where $\Delta L^* = Li^* - L0^*$, $\Delta a^* = ai^* - a0^*$, $\Delta b^* = bi^* - b0^*$, "i" is the time chosen for the color variation analysis and "0" the measurements taken before the specimens were exposed to the test.

For the durability study, 21 samples were tested, 3 for each paint formulation, each measuring 3.5 cm in width and 20 cm in length. Figure 3 illustrates the test methods regarding weathering and color monitoring.

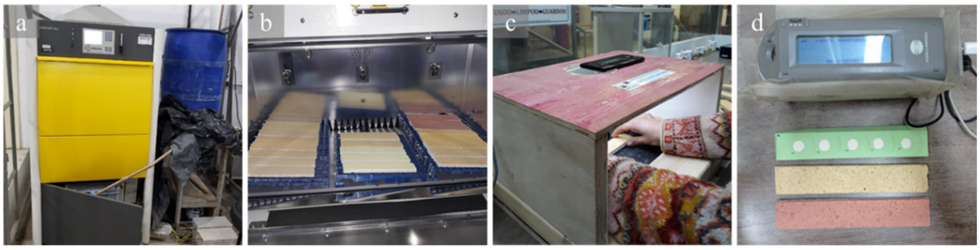

Figure 3. (**a**) Weathering chamber; (**b**) disposal of specimens inside the weathering chamber; (**c**) photograph capture; (**d**) colorimetric analysis using a spectrophotometer.

The weathering chamber cycles were stopped just before precipitation to ensure the specimens were dry, and with coherent appearances in all monitoring times, 16 periodic evaluations were made to analyze changes, such as paint deterioration and color variations.

After each evaluation, the specimens were randomly rearranged within the chamber, resulting in a total test duration of 347 h. The cycles were conducted until a visual difference in the coloration of the samples was noticed, indicating a significant alteration due to artificial aging. The deionized water used to simulate precipitation was not recycled during the test to prevent potential contamination from any paint particles released.

A total of 174 cycles of artificial aging were conducted, with the final cycle not being completed in order to remove the samples before the simulated rain, ensuring that they were dry to perform the colorimetric analysis.

3. Results and Discussion

3.1. Water Vapor Permeability

Table 2 shows the results for the vapor permeability and vapor diffusion resistance factor of the paints studied, as well as the analysis of an unpainted substrate used as a reference.

Table 2. Vapor permeability and vapor diffusion resistance factor.

	Vapor Permeability			**Vapor Diffusion Resistance Factor (m)**		
	Average (ng/s.m·Pa)	**Standard Deviation (kg/s.m·Pa)**	**Variation Coefficient**	**Average**	**Standard Deviation**	**Variation Coefficient**
REF	23.33	3.18	14%	8.44	1.12	13%
YS	23.07	1.37	6%	8.44	0.50	6%
BS	20.81	1.63	8%	9.37	0.72	8%
PVA	18.35	2.33	13%	10.71	1.32	12%
MA_1	18.62	3.53	19%	10.74	2.18	20%
L	23.06	3.11	14%	8.52	1.03	12%
MA_2	23.03	0.58	3%	8.44	0.22	3%
YS_3	23.77	2.50	11%	8.23	0.82	10%

Table 2 shows that the highest vapor permeability was obtained for the specimens with three coats of yellow silicate paint (YS_3), without the paint (REF), and with two coats of yellow silicate paint (YS), respectively. Through the Analysis of Variance (ANOVA), with a significance level of 5%, shown in Table 3, it is possible to identify a significant influence on the results of resistance to vapor diffusion due to the application of the paints.

Table 3. Analysis of Variance (ANOVA) for vapor diffusion resistance factor.

Effect	Square Sum	Degrees of Freedom	Mean Square	Test F	Probability	Significant Influence
Paint	30.921	7	4.417	3.417	0.01121	**Yes**
Error	31.03	24	1.293			

The multiple analysis of means conducted using the Fisher LSD method (Table 4) indicated that, regarding the vapor diffusion resistance factor, there was a significant difference between the specimens with PVA paint and matte acrylic (MA_1) compared to all the other formulations, except the brown silicate paint (BS). This was not observed for the other systems.

Table 4. Multiple analysis of means of the vapor diffusion resistance factor (S: significant; NS: not significant).

	Sample	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}
1	REF		NS	NS	S	S	NS	NS	NS
2	YS	NS		NS	S	S	NS	NS	NS
3	BS	NS	NS		NS	NS	NS	NS	NS
4	PVA	S	S	NS		NS	S	S	S
5	MA_1	S	S	NS	NS		S	S	S
6	L	NS	NS	NS	S	S		NS	NS
7	MA_2	NS	NS	NS	S	S	NS		NS
8	YS_3	NS	NS	NS	S	S	NS	NS	

The results obtained are consistent with the behavior observed by [20,36,37], who found that the paints evaluated had lower and higher extremes for acrylic and silicate paints, respectively. Furthermore, in the study conducted by [37], there was no statistically significant difference between the vapor permeability of PVA, matte acrylic, and silicate paints. However, PVA and silicate paints demonstrated relatively similar results to lime-based paints. Therefore, there is consistency between the results of this study and other investigations, with possible variations related to factors such as the specific composition of the paints evaluated and their application methods.

Historical mortars available in the database of the Fraunhofer Institute for Building Physics [38] exhibit vapor diffusion resistance factors ranging from 7.02 (lime + crushed bricks), 7.4 (lime + pozzolan), and 7.8 (gypsum) to 9.61 (lime + gypsum). On average, the substrate used in this research, cellular concrete, met the objectives concerning the expected vapor diffusion resistance factor. When considering the use of the paint types investigated in historic buildings, the compositions YS, BS, L, MA_2, and YS_3 can be regarded as the most suitable in terms of vapor permeability since they did not exhibit a statistically significant difference compared to the reference (REF). However, YS, BS, L, and YS_3 paints could be recommended due to their mineral rather than synthetic origin, unlike MA_2.

The water vapor permeability test is one of the primary tests necessary for assessing mortars for use in paint coatings. Paints applied to the exteriors of historic facades must exhibit adequate water vapor permeability, thereby preventing internal condensation and the subsequent development of pathological issues.

3.2. Washability

The washability test of the paints revealed that the PVA, MA_1, and MA_2 formulations exhibited no change or material loss after 200 rubs with wet surgical gauze. In contrast, the remaining configurations, YS, YS_3, BS, and L, had signs of wear after being rubbed from 10 to 20 times with the gauze (Figure 4), possibly suggesting a diminished washability performance. It is important to note that this analysis can be considered simplified and should be supplemented with the results of accelerated aging and durability tests.

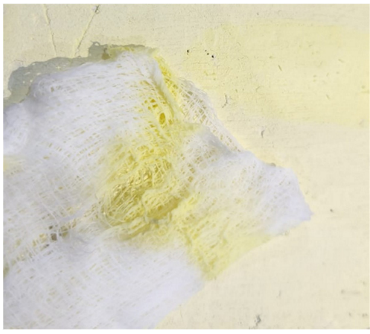

Figure 4. Washability of paint specimen with lime + yellow dye formulation.

3.3. Paints' Adhesion to the Substrate

In the test carried out according to ASTM D4541 standard [33], all seven paints applied to the cellular concrete substrate were tested. The pull-off resistance values, using the pull-off adhesion test, are shown in Table 5.

Table 5. Pull-off adhesion test.

Paint	Strength (MPa)			Average	Standard Deviation	Variation Coefficient
YS	0.95	1.1	1.18	1.08	0.12	11%
BS	1.07	1.35	0.92	1.11	0.22	20%
PVA	0.7	1.22	1.11	1.01	0.27	27%
MA_1	0.95	1.09	1.04	1.03	0.07	7%
L	0.09	0	0.07	0.08	0.01	18%
MA_2	0.87	1.03	1.13	1.01	0.13	13%
YS_3	1.18	1.15	0.96	1.10	0.12	11%

For six of the seven paint formulations, except for the lime paint, there was adhesion failure within the substrate. This hindered a direct assessment of the adhesion between the coating and the substrate because, due to the low mechanical strength of cellular concrete, along with its porosity and uneven texture, the coating did not detach from the paint film (Figure 5).

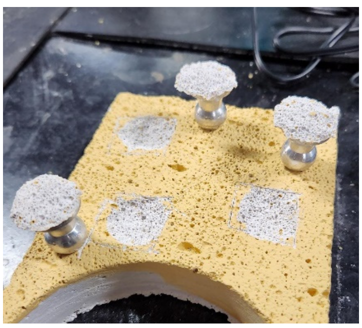

Figure 5. Pulling out of the substrate during the test.

However, in the case of the lime paint, the paint layer stood out due to its greater thickness and density compared to the other coatings. The adhesion strength value was low, at 0.08 MPa, but it still allowed for an effective assessment, as outlined in the ASTM D4541 standard [33]. It is worth noting that, despite the challenges faced during this test, the results obtained can offer valuable insights for the planning of future projects in historic environments with similar substrates.

3.4. Exposure to Accelerated Artificial Aging and Color Monitoring

Figure 6 depicts the color variations of the paint formulations at the measurement points after the exposure period. The lime paint exhibited the most significant color variation, followed by the matte acrylic paints (MA_2 and MA_1). When evaluating the durability of paints and coatings, the assessment of fading becomes particularly crucial. As per NBR 13749 [39], pigments are expected to withstand the UV radiation to which they are exposed.

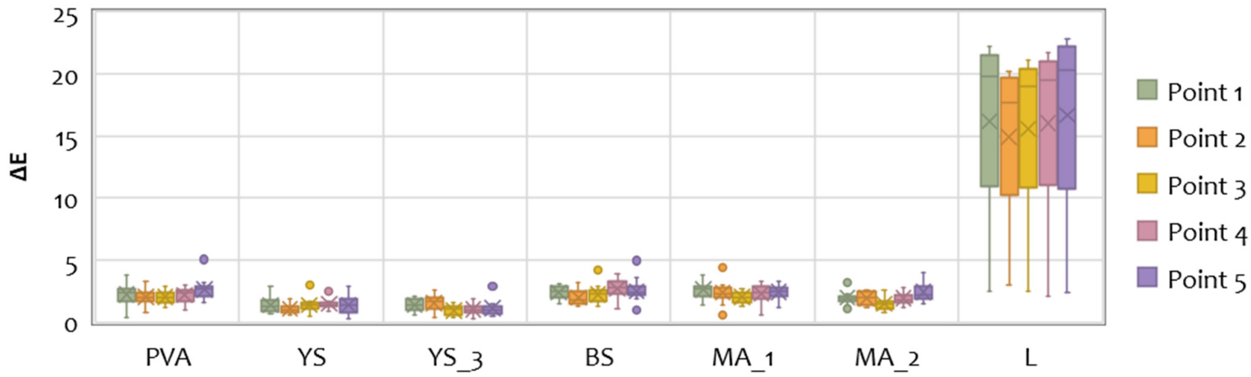

Figure 6. Color variation.

Figure 7 presents a photographic comparison of the specimens between monitoring time 16 and reading "0" (before exposure to the test). The visual analysis aligns with the colorimetric analysis, clearly illustrating the significant pigment loss in the lime paint. Similar findings were also reported by Brito [20], who observed pronounced fading and staining in lime-based paints. In contrast, samples with silicate-based paint, primarily reddish in color, exhibited better performance, despite showing some changes in color and white spots, resembling the results obtained in this study for brown silicate paint (BS).

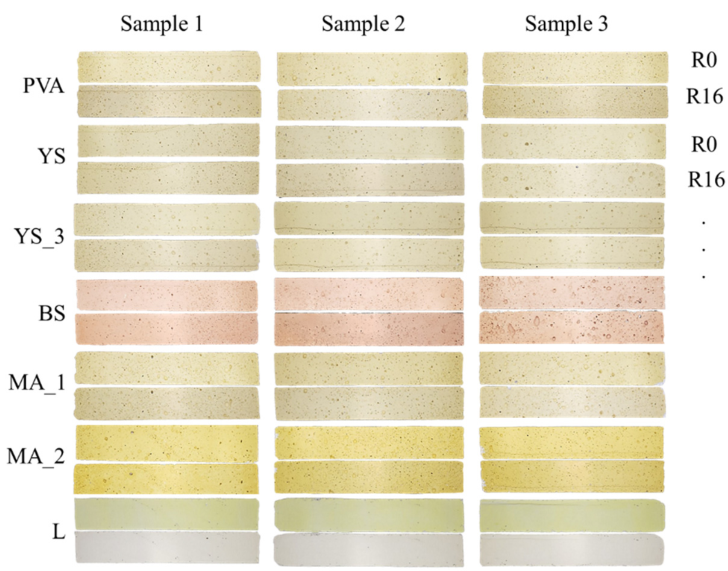

Figure 7. Color variation by image analysis (R: reading).

The Analysis of Variance (ANOVA) among the specimens (Table 6), with a 95% confidence interval, shows which samples had a significant color variation.

Table 6. Analysis of Variance (ANOVA) for color variation (S: significant; NS: not significant).

Tinta	Valor-p	
AF_1-AF_2	0.641655	NS
Cal-AF_2	0.00000	S
PVA-AF_2	0.999939	NS
SA-AF_2	0.661436	NS
SA_3-AF_2	0.684828	NS
SM_1-AF_2	1.000000	NS
Cal-AF_1	0.00000	S
PVA-AF_1	0.460275	NS
SA-AF_1	0.03706	S
SA_3-AF_1	0.04047	S
SM_1-AF_1	0.717789	NS
PVA-Cal	0.00000	S
SA-Cal	0.00000	S
SA_3-Cal	0.00000	S
SM-Cal	0.00000	S
SA-PVA	0.825717	NS
SA_3-PVA	0.843832	NS
SM-PVA	0.999514	NS
SA_3-SA	1.000000	NS
SM-SA	0.58321	NS
SM-SA_3	0.607235	NS

Most notable differences become apparent when comparing the lime paint with the others. Furthermore, the matte acrylic paint MA_1 exhibits a statistically significant difference compared to the yellow silicate paint applied with two coats (YS) and three coats (YS_3). It is worth noting that when comparing the YS and YS_3 samples, no significant change is observed after 16 cycles. In other words, the application of two coats of paint was enough to create a durable film regarding the chosen accelerated aging cycle.

4. Conclusions

Paints play an important aesthetic and protective role regarding facade renderings, and their compatibility with the substrate is essential for satisfactory performance. Using paints with adequate characteristics becomes especially important when considering their application to historic buildings.

The comprehensive understanding of paint properties, as explored in our study, is instrumental in expanding the competences of those involved in conservation work. It not only equips them with the technical knowledge required for selecting appropriate materials but also enhances their ability to plan and execute conservation projects that effectively balance aesthetic, protective, and sustainable considerations.

Based on the results obtained in this study, matte acrylic paint exhibited the poorest performance in terms of water vapor permeability, especially when considering its potential use on historic facades. It contributed to the highest vapor diffusion resistance factor, a characteristic shared with PVA paint. Recognizing that water is a major contributor to structural issues in buildings, it becomes imperative that coatings facilitate its escape from the facade's cross-section and allow the substrate to dry adequately. In general, among the paints analyzed, the silicate-based and lime-based paints demonstrated the highest levels of vapor permeability.

However, when accelerated aging was assessed, the lime-based paints showed an almost total loss of yellow color, corroborating what was identified in the washability test. On the other hand, the silicate paints had also shown wear in the washability test but showed adequate behavior throughout aging. Therefore, based on the results obtained from the tests, silicate-based paints could be the most recommended for application in historic mortar coatings.

In terms of adhesion to the substrate, the lime paint was the only one that experienced peeling within the paint layer, possibly because of the greater thickness resulting from the painting process. Consequently, the adhesion test to the substrate was compromised due to the mechanical strength limitations of the cellular concrete substrate, which exhibited tearing at the expense of the paint layers, except for the lime paint. Therefore, it is recommended that future research includes additional studies on adhesion, potentially exploring different substrates, such as mortars with compositions similar to historical ones.

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References

1. Eusébio, M.I.; Rodrigues, M.P. Patologia de revestimentos de pintura de edifícios e esquemas de pintura adequados. In *Proceedings of the III Jornadas PINTUMED (APTETI) Mudanças no Mercado das Tintas*; Laboratório Nacional de Engenharia Civil de Lisboa: Lisbon, Portugal, 2005.
2. Torres, S.A.D.O. Caracterização da Influência dos Corantes nas Propriedades Físicas das Tintas e Durabilidade de Cor. Master's Thesis, Universidade Nova de Lisboa, Lisbon, Portugal, 2018.
3. Moura, A.; Flores-Colen, I.; De Brito, J.; Dionisio, A. Study of the cleaning effectiveness of limestone and lime-based mortar substrates protected with anti-graffiti products. *J. Cult. Herit.* **2017**, *24*, 31–44. [CrossRef]
4. Shrestha, R.; Shen, Z.; Bhatta, K.D. Cultural Heritage Deterioration in the Historical Town 'Thimi'. *Buildings* **2024**, *14*, 244. [CrossRef]
5. Lambourne, R.; Strivens, T.A. *Paint and Surface Coatings: Theory and Practice*; Elsevier: Amsterdam, The Netherlands, 1999.
6. Marrion, A. *The Chemistry and Physics of Coatings*; Royal Society of Chemistry: London, UK, 2004.
7. Bordin, M.F.; Lantelme, E.M.V.; Costella, M.F. A especificação do desempenho e vida útil dos sistemas de pintura externa de acordo com a norma brasileira de desempenho-NBR 15575. *Amb. Const.* **2021**, *21*, 125–142. [CrossRef]
8. ABRAFATI. O Setor de Tintas no Brasil. Available online: https://abrafati.com.br/setor-de-tintas/dados-do-setor/ (accessed on 12 December 2023).
9. Marques, F.P.F.M. Tecnologias de Aplicação de Pinturas e Patologias em Paredes de Alvenaria e Elementos de Betão. Master's Thesis, Instituto Superior Técnico de Lisboa, Lisbon, Portugal, 2013.
10. Amaro, M.F. Estudo Comparativo de Tintas para Fachadas—Volume I. Master's Thesis, Instituto Superior Técnico de Lisboa, Lisbon, Portugal, 2007.
11. Goldschmidt, A.; Streitbeger, H.J. *BASF Handbook on Basics of Coating Technology*; Vincentz: Hannover, Germany, 2007.

12. Talbert, R. *Paint Technology Handbook, Ecosystems and Human Well-Being: A Framework for Assessment*; CRC Press: Boca Raton, FL, USA, 2007.
13. Paulino, A.F.R.S. Estudo de Mercado de Tintas de Base Aquosa com Diferentes CPV. Ph.D. Thesis, Universidade NOVA de Lisboa, Lisbon, Portugal, 2018.
14. Millennium Ecosystem Assessment Board. *Ecosystems and Human Well-Being: A Framework for Assessment*; Island Press: Washington, DC, USA, 2003.
15. Yamak, H.B. Emulsion polymerization: Effects of polymerization variables on the properties of vinyl acetate based emulsion polymers. In *Polymer Science*; IntechOpen: London, UK, 2013; pp. 35–72. [CrossRef]
16. Uemoto, K.L. *Projeto, Execução e Inspeção de Pinturas*; O Nome da Rosa: São Paulo, Brazil, 2002.
17. Morais, A.P.F. Análise da Influência do Tipo de Revestimento por Pintura no Desempenho de Suportes Porosos. Ph.D Thesis, Universidade Nova de Lisboa, Lisboa, Portugal, 2019.
18. Uemoto, K.L.; Agopyan, V.; Vittorino, F. Concrete protection using acrylic latex paints: Effect of the pigment volume content on water permeability. *J. Mater. Struct.* **2001**, *34*, 172–177. [CrossRef]
19. Ribeiro, A.; Eusébio, I. Tintas inorgânicas: Tintas de cal e de silicatos. *Cad. Edifícios* **2002**, *2*, 117–139.
20. Brito, V. Influência dos Revestimentos por Pintura na Secagem do Suporte. Master's Thesis, Universidade NOVA de Lisboa, Lisbon, Portugal, 2009.
21. Nunes, C.L.; Mlsnová, K.; Slížková, Z. Limewashes with Linseed Oil and Its Effect on Water and Salt Transport. *Buildings* **2022**, *12*, 402. [CrossRef]
22. Gil, M. As pinturas a cal nos Tratados e Manuais Técnicos da Construção Civil em Portugal entre 1880 e 1931–Uma revisão histórica. *Conserv. Patrim.* **2022**, *39*, 45–60. [CrossRef]
23. Verdum, G.; Bersch, J.D.; Guerra, F.L.; Socoloski, R.F.; Giordani, C.; Zucchetti, L.; Masuero, A.B. Mortar Coating Degradation in Historical Buildings Facades from Rio Grande Do Sul—Brazil. *Constr. Build. Mater.* **2021**, *310*, 125221. [CrossRef]
24. Prieto, A.J.; Verichev, K.; Carpio, M. Heritage, Resilience and Climate Change: A Fuzzy Logic Application in Timber-Framed Masonry Buildings in Valparaíso, Chile. *Build. Environ.* **2020**, *174*, 106657. [CrossRef]
25. Aste, N.; Adhikari, R.S.; Buzzetti, M.; Della Torre, S.; Del Pero, C.; Huerto, C.H.E.; Leonforte, F. Microclimatic Monitoring of the Duomo (Milan Cathedral): Risks-Based Analysis for the Conservation of Its Cultural Heritage. *Build. Environ.* **2019**, *148*, 240–257. [CrossRef]
26. Rocha, M.; Faria, P.; Gago, A.S. Conservation of Defensive Military Structures Built with Rammed Earth. *Buildings* **2024**, *14*, 238. [CrossRef]
27. Lourenço, P.B.; Luso, E.; Almeida, M.G. Defects and Moisture Problems in Buildings from Historical City Centres: A Case Study in Portugal. *Build. Environ.* **2006**, *41*, 223–234. [CrossRef]
28. Silva Loureiro, A.M.; Aranha da Paz, S.P.; do Rosario Veiga, M.; Angélica, R.S. Investigation of Historical Mortars from Belém Do Pará, Northern Brazil. *Constr. Build. Mater.* **2020**, *233*, 117284. [CrossRef]
29. Schueremans, L.; Cizer, Ö.; Janssens, E.; Serré, G.; Balen, K. Van Characterization of Repair Mortars for the Assessment of Their Compatibility in Restoration Projects: Research and Practice. *Constr. Build. Mater.* **2011**, *25*, 4338–4350. [CrossRef]
30. Borges, C.; Santos Silva, A.; Veiga, R. Durability of Ancient Lime Mortars in Humid Environment. *Constr. Build. Mater.* **2014**, *66*, 606–620. [CrossRef]
31. *ASTM E96/E96M*; Standard Test Methods for Water Vapor Transmission of Materials. ASTM International: West Conshohocken, PA, USA, 2016.
32. Polito, G. *Principais Sistemas de Pinturas e Suas Patologias*; Specialization Monograph; Universidade Federal de Minas Gerais: Belo Horizonte, Brazil, 2006.
33. *ASTM D4541*; Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers. ASTM International: West Conshohocken, PA, USA, 2022.
34. *ASTM D6695*; Standard Practice for Xenon-Arc Exposures of Paint and Related Coatings. ASTM International: West Conshohocken, PA, USA, 2016.
35. Maury-Ramirez, A.; Demeestere, K.; De Belie, N. Photocatalytic activity of titanium dioxide nanoparticle coatings applied on autoclaved aerated concrete: Effect of weathering on coating physical characteristics and gaseous toluene removal. *J. Hazard. Mater.* **2012**, *211–212*, 218–225. [CrossRef] [PubMed]
36. Remédios, N. Avaliação do Desempenho de Sistemas de Acabamento de Rebocos à Base de Cal para Edifícios Antigos. Master's Thesis, Universidade NOVA de Lisboa, Lisbon, Portugal, 2016.
37. Bersch, J.D.; Andrade Neto, J.S.; Da Silva, T.S.M.; Masuero, A.B. Effect of Different Types of Paint on the Hygrothermal Behaviour of Facade Rendering Mortars in Brazil. *J. Archit Eng.* **2024**, *30*, 04024005. [CrossRef]
38. IBP. *WUFI® Pro*; v6.6 (Version 6.6); Non Commercial; Institute for Building Physics: Stuttgart, Germany, 2023.
39. *NBR 13749*; Revestimento de Paredes e Tetos de Argamassas Inorgânicas—Especificação. ABNT: Rio de Janeiro, Brazil, 2013.