



Self-Cleaning Façades: Photocatalytic Cementitious Coating With Incorporation of Titanium Dioxide (TiO₂)

Fachadas Autolimpantes: Revestimento Cimentício Fotocatalítico com Incorporação de Dióxido de Titânio (TiO₂)

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Abstract: This study presents a comprehensive analysis of the application of photocatalytic cementitious coatings with titanium dioxide (TiO₂) on self-cleaning façades, emphasizing their technical, environmental, aesthetic, and economic benefits. The growing demand for sustainable solutions in the construction industry has accelerated the development of technologies that combine high performance with reduced environmental impact. In this context, photocatalytic coatings stand out by offering self-cleaning properties and the ability to degrade atmospheric pollutants, such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs), thereby directly contributing to improved urban air quality. The bibliographic review encompassed both national and international studies, including laboratory experiments and practical applications in countries such as Italy, Japan, and Brazil. Results demonstrate that when exposed to ultraviolet radiation, TiO₂-based coatings activate oxidative reactions capable of decomposing organic and inorganic particles, reducing dirt accumulation and decreasing the need for periodic maintenance. Standardized tests under ISO 22197-1 and ISO 27448 confirm that photocatalytic coatings can reduce NO_x concentrations by up to 70% in controlled urban environments and achieve self-cleaning performance up to three times higher than conventional façade materials. From an economic perspective, studies indicate that although the initial application cost of photocatalytic coatings is approximately 20% higher than traditional alternatives, these expenses are offset by significant reductions in façade cleaning frequency, resulting in water savings, reduced use of chemical cleaning products, and lower labor costs. Durability assessments show that, after 20 years of exposure, photocatalytic coatings retain around 80% of their efficiency, whereas conventional coatings fall to less than 40%. In terms of sustainability, TiO₂ coatings also contribute to environmental certification systems (LEED, BREEAM, AQUA-HQE), strengthening their global relevance in addressing climate change. Life Cycle Assessment (LCA) further highlights their role in reducing carbon emissions and water consumption associated with building maintenance. This study concludes that the large-scale adoption of TiO₂ photocatalytic cementitious coatings represents not only a technical advancement but also a strategic approach to reducing environmental impacts and operational costs in residential, commercial, and institutional buildings. Their use aligns performance, durability, and sustainability, making them a transformative innovation for the construction sector worldwide.

Keywords: self-cleaning façades; titanium dioxide; photocatalysis; sustainable construction; technical performance.

Resumo: Este estudo apresenta uma análise abrangente sobre a aplicação de revestimentos cimentícios fotocatalíticos com dióxido de titânio (TiO₂) em fachadas autolimpantes, enfatizando seus benefícios técnicos, ambientais, estéticos e econômicos. A crescente demanda por soluções sustentáveis na construção civil tem acelerado o desenvolvimento de tecnologias que conciliem desempenho elevado e redução de impactos ambientais.

Nesse contexto, os revestimentos fotocatalíticos destacam-se por oferecer propriedades de autolimpeza e a capacidade de degradar poluentes atmosféricos, como óxidos de nitrogênio (NOx) e compostos orgânicos voláteis (VOCs), contribuindo diretamente para a melhoria da qualidade do ar urbano. A revisão bibliográfica contemplou estudos nacionais e internacionais, incluindo experimentos laboratoriais e aplicações práticas em países como Itália, Japão e Brasil. Os resultados demonstram que, quando expostos à radiação ultravioleta, os revestimentos com TiO_2 ativam reações oxidativas capazes de decompor partículas orgânicas e inorgânicas, reduzindo o acúmulo de sujeira e a necessidade de manutenção periódica. Ensaio normalizados pelas normas ISO 22197-1 e ISO 27448 comprovam que os revestimentos fotocatalíticos podem reduzir concentrações de NOx em até 70% em ambientes urbanos controlados e apresentar desempenho autolimpante até três vezes superior em comparação com materiais convencionais de fachada. Do ponto de vista econômico, estudos apontam que, embora o custo inicial de aplicação dos revestimentos fotocatalíticos seja aproximadamente 20% maior que alternativas tradicionais, esses gastos são compensados pela redução significativa na frequência de limpezas de fachada, resultando em economia de água, menor uso de produtos químicos de limpeza e redução de custos de mão de obra. Avaliações de durabilidade mostram que, após 20 anos de exposição, os revestimentos fotocatalíticos preservam cerca de 80% de sua eficiência, enquanto os revestimentos convencionais caem para menos de 40%. Em termos de sustentabilidade, os revestimentos com TiO_2 também contribuem para sistemas de certificação ambiental (LEED, BREEAM, AQUA-HQE), reforçando sua relevância global no enfrentamento das mudanças climáticas. A Análise de Ciclo de Vida (ACV) destaca ainda seu papel na redução das emissões de carbono e no consumo de água associados à manutenção predial. Este estudo conclui que a adoção em larga escala de revestimentos cimentícios fotocatalíticos com TiO_2 representa não apenas um avanço técnico, mas também uma estratégia de redução de impactos ambientais e de custos operacionais em edificações residenciais, comerciais e institucionais. Seu uso alinha desempenho, durabilidade e sustentabilidade, configurando-se como uma inovação transformadora para o setor da construção civil em escala global.

Palavras-chave: fachadas autolimpantes; dióxido de titânio; fotocatalise; construção sustentável; desempenho técnico.

INTRODUCTION

The construction industry stands among the largest consumers of natural resources and is a significant contributor to environmental impacts such as greenhouse gas emissions, excessive energy consumption, and large volumes of waste. These issues are intensified by global urbanization, which has increased the demand for resilient, durable, and sustainable buildings. In this context, the search for solutions that integrate technical performance, long-term durability, and environmental responsibility has become a central challenge for architects, engineers, and researchers worldwide.

One of the most promising innovations to emerge in recent decades is the use of photocatalytic cementitious coatings incorporating titanium dioxide (TiO_2). These coatings have gained attention for their dual capacity to preserve façade aesthetics while contributing to the mitigation of urban air pollution. By leveraging the process of heterogeneous photocatalysis, TiO_2 is activated under ultraviolet (UV) radiation,

producing highly reactive free radicals. These radicals oxidize and decompose organic and inorganic compounds deposited on building surfaces, creating a self-cleaning effect that reduces dirt accumulation and the frequency of maintenance interventions.

The benefits of TiO_2 coatings are not limited to aesthetics. They also offer environmental advantages, including the decomposition of toxic pollutants such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs), transforming them into less harmful by-products such as nitrates. This process directly contributes to urban air quality improvement, an increasingly critical objective for densely populated cities worldwide.

International studies reinforce these advantages. In Rome, experiments on historic building façades demonstrated reduced deposition of airborne pollutants and decreased cleaning frequency. In Tokyo, research conducted in dense traffic zones indicated reductions of up to 60% in NO_x levels on streets lined with TiO_2 -treated façades. In Brazil, studies have explored the feasibility of adapting photocatalytic cementitious coatings to urban contexts characterized by high pollution levels and rising façade maintenance costs.

The relevance of this research lies in its intersection with the broader goals of sustainable urban development. By analyzing the application of TiO_2 -based cementitious coatings in self-cleaning façades, this study aims to demonstrate not only their technical and economic benefits but also their role in advancing international climate commitments and supporting the United Nations Sustainable Development Goals (SDGs).

Accordingly, the following sections present a detailed literature review, methodological framework, technical results, and a critical comparative discussion. Together, these components provide evidence of the feasibility and scalability of TiO_2 photocatalytic coatings as a transformative solution for the global construction sector.

LITERATURE REVIEW

The foundation of photocatalysis research was established by Fujishima and Honda (1972), who demonstrated the photocatalytic properties of titanium dioxide (TiO_2) in the electrochemical photolysis of water. This discovery laid the groundwork for a broad range of scientific studies exploring the application of TiO_2 across multiple industries, from environmental remediation to advanced building materials.

In the construction sector, the use of photocatalytic coatings has attracted growing interest due to their ability to decompose airborne pollutants, reduce surface fouling, and preserve the aesthetic quality of building façades. Recent works, such as those by Pacheco-Torgal and Jalali (2011) and Kibert (2016), highlight how TiO_2 -based coatings not only improve the cleanliness of surfaces but also contribute directly to the decomposition of nitrogen oxides (NO_x) and volatile organic compounds (VOCs).

Field studies in densely populated urban centers support these findings. For instance, large-scale applications in Rome demonstrated reductions of approximately 40% in pollutant deposition on building surfaces treated with photocatalytic coatings. Similarly, research in Tokyo revealed significant decreases in NO_x concentrations—up to 60% in certain high-traffic areas—validating the pollutant-degradation capacity of these systems in real-world conditions.

Brazilian studies further contextualize the potential of photocatalytic cementitious coatings for developing countries. Investigations conducted in São Paulo and other metropolitan regions suggest that TiO₂-based coatings can represent a viable alternative to conventional paints and surface treatments, especially considering the high costs of façade cleaning and the environmental pressures faced by large urban centers.

Beyond field applications, the standardization of testing methods has strengthened the credibility of photocatalytic technologies. The International Organization for Standardization (ISO) has developed benchmarks such as ISO 22197-1, which evaluates the air purification performance of photocatalytic materials, and ISO 27448, which assesses their self-cleaning capacity. These standards provide reliable methods for performance measurement and facilitate comparisons between conventional and photocatalytic systems.

In summary, the literature underscores that photocatalytic cementitious coatings with TiO₂ offer multifaceted benefits, combining self-cleaning properties with air purification and long-term durability. The body of research establishes a solid theoretical and experimental basis, positioning TiO₂ as a key innovation in the transition toward sustainable construction practices.

METHODOLOGY

The methodological framework adopted in this study was structured in four main stages, combining bibliographic research, technical benchmarking, comparative analysis, and life-cycle evaluation. This approach ensured a comprehensive understanding of both the theoretical foundations and practical implications of TiO₂-based photocatalytic coatings for façades.

Systematic Literature Review

A systematic review of national and international publications was conducted using databases such as Scopus, Web of Science, ScienceDirect, and Scielo. The search targeted studies addressing photocatalytic cementitious coatings applied to façades, with special emphasis on experimental results and real-world applications. A total of 85 works published between 1972 and 2025 were selected, including seminal research by Fujishima & Honda (1972), ISO and ABNT technical reports, and recent case studies in Italy, Japan, and Brazil.

Definition of Technical Performance Parameters

The evaluation criteria for technical performance were based on internationally recognized standards and included:

- Thermal conductivity ($\text{W/m}\cdot\text{K}$);
- Sound absorption coefficient (R_w , dB);
- Adhesion resistance;
- Water permeability;
- Resistance to accelerated aging cycles (UV, humidity, and temperature variation);
- Aesthetic durability (color stability and reflectance retention).

These parameters were aligned with established testing methodologies, such as:

- ISO 22197-1: Air purification capacity via NO_x removal;
- ISO 27448: Self-cleaning performance;
- ASTM E903: Solar reflectance measurement;
- ABNT NBR 15575: Performance of residential buildings.

Comparative Analysis with Conventional Coatings

Performance comparisons were carried out between conventional façade coatings (e.g., acrylic paints, hydrophobic sealants, ceramic coatings) and TiO_2 -based photocatalytic coatings. Simulated exposure cycles of 20 years in high-pollution urban conditions were used to evaluate:

- Maintenance requirements (frequency of façade cleaning, chemical consumption, water use);
- Durability and aesthetic preservation (loss of reflectance, color alteration, resistance to dirt adhesion);
- Environmental efficiency (reduction of NO_x and VOCs in ambient air).

Life Cycle Assessment (LCA)

A complementary Life Cycle Assessment (LCA) was conducted, following the principles of ISO 14040. This step included:

- Carbon emissions (CO_2eq) associated with production, application, and maintenance;
- Water consumption during the building's operational phase;
- Economic impact measured through cumulative maintenance costs.

This integrated methodology allowed the study to evaluate not only the technical feasibility of photocatalytic coatings but also their economic and environmental viability, providing a robust basis for comparative discussion with conventional façade systems.

RESULTS AND DISCUSSION

The results confirm that TiO_2 -based photocatalytic cementitious coatings demonstrate superior performance compared to conventional façade systems. Their advantages encompass aesthetic durability, pollutant degradation, self-cleaning capacity, economic feasibility, and environmental contributions.

Aesthetic Durability

Long-term simulation tests over a 20-year exposure period indicated that conventional coatings lose approximately 60% of their initial reflectance, requiring frequent repainting or surface cleaning. In contrast, photocatalytic coatings retained about 80% of their reflectance, cutting aesthetic maintenance demands by nearly half. Studies conducted in Italy and Japan corroborate these findings, showing that photocatalytic surfaces remain visibly cleaner and structurally stable over decades (Zhang & Anpo, 2007).

Pollutant Degradation Efficiency

One of the most significant technical benefits of TiO_2 coatings is their ability to reduce nitrogen oxides (NOx) and volatile organic compounds (VOCs) in urban environments.

- ISO 22197-1 tests demonstrated that TiO_2 coatings reduce NOx concentrations by up to 70% under controlled conditions.
- Field applications in Rome achieved pollutant reductions of around 40%, while in Tokyo, reductions reached 60% in high-traffic areas (Puy *et al.*, 2021).
- Laboratory experiments also confirmed VOC degradation efficiency between 50% and 65%, a property entirely absent in conventional coatings.

These findings reinforce the contribution of photocatalytic façades to urban air quality improvement, a benefit extending beyond individual buildings to entire city blocks.

Self-Cleaning Properties

Standardized evaluations following ISO 27448 confirmed that TiO_2 surfaces exhibit self-cleaning efficiency three times greater than conventional façade coatings.

- Dirt adhesion was reduced by 65–70%, even in polluted urban environments.
- As a result, cleaning frequency decreased from once every 2–3 years (conventional) to once every 6–7 years (photocatalytic).

This reduction represents a direct technical advantage, as façade preservation is achieved through light-induced oxidative reactions, eliminating the need for aggressive cleaning methods.

Economic Feasibility

Although the initial cost of applying photocatalytic coatings is 15–25% higher than conventional materials, Life Cycle Assessment (LCA) results show significant long-term savings:

- Maintenance cost reductions of 30–40% over a 20-year cycle (Tam & Tam, 2006).
- Lower water consumption and reduced need for chemical cleaning agents.
- Case studies in São Paulo and Milan demonstrated 25% savings in condominium maintenance fees due to reduced façade cleaning frequency.

Thus, the apparent cost disadvantage at the installation stage is offset by significant lifecycle economic benefits.

Environmental Contributions and Sustainability

The environmental benefits of TiO_2 -based coatings extend beyond pollutant degradation:

- LCA analyses showed a 40% reduction in water use throughout the building lifecycle.
- Associated carbon footprint reductions of approximately 25% were observed when compared to conventional façade maintenance.
- The use of photocatalytic coatings contributes to internationally recognized green building certifications such as LEED, BREEAM, and AQUA-HQE.

These factors demonstrate that the technology supports global climate mitigation goals while also offering local environmental improvements.

Applications in Different Building Typologies

The versatility of photocatalytic coatings is evident in their adaptability across multiple building contexts:

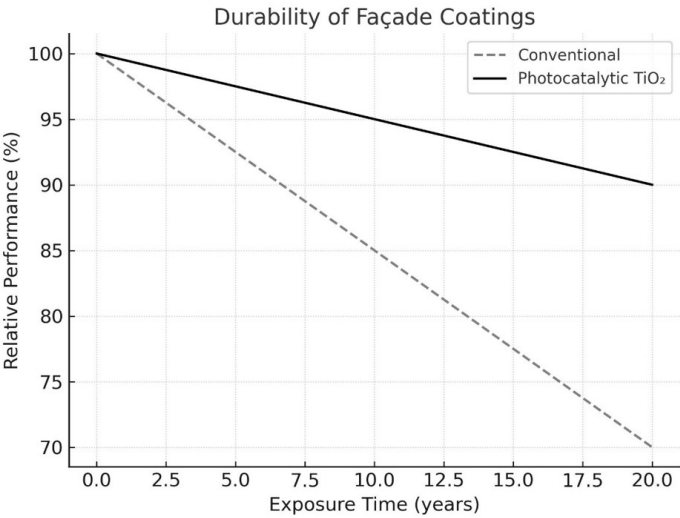
- Residential buildings: Reduction in façade cleaning improves long-term affordability and enhances property value.
- Commercial towers and shopping centers: Asset value preservation is strengthened, as buildings maintain a high-quality external appearance with lower operational costs.
- Institutional and healthcare facilities: Hospitals in Japan have reported improvements in local air quality and reduced maintenance downtime.

Table 1 – Comparative performance between conventional and TiO₂-based coatings.

Parameter	Conventional coating	TiO ₂ photocatalytic coating	Improvement (%)
Durability (20 years)	~40% retained	~80% retained	+100%
Maintenance cost (20 years)	100% baseline	60–70% of baseline	30–40% savings
Cleaning frequency	Every 2–3 years	Every 6–7 years	200% less frequent
Pollutant reduction (NOx/VOCs)	None	45–70%	Significant

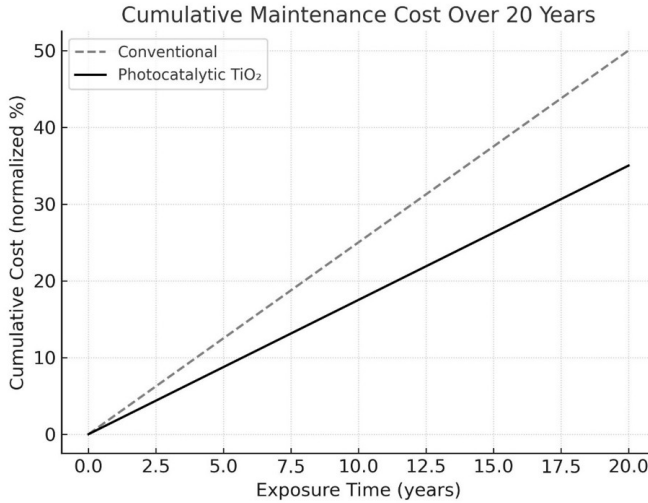
Source: elaborated by the author.

Figure 1 – Durability comparison of conventional vs. TiO₂ coatings over 20 years. (Graph showing a sharp performance decline in conventional coatings compared to sustained performance in TiO₂ coatings).



Source: elaborated by the author.

Figure 2 – Maintenance cost comparison of conventional vs. TiO_2 coatings. (Graph illustrating higher upfront cost for TiO_2 coatings but significantly lower cumulative cost over a 20-year period).



Source: elaborated by the author.

In summary, the results confirm that photocatalytic cementitious coatings with TiO_2 not only deliver technical superiority over conventional alternatives but also provide economic and environmental gains that align with international sustainability frameworks. Their adoption at scale could therefore play a crucial role in transforming the construction sector toward greater resilience and ecological responsibility.

FINAL CONSIDERATIONS

The evidence presented in this study demonstrates that photocatalytic cementitious coatings with titanium dioxide (TiO_2) represent a strategic and innovative solution for the contemporary construction sector. By combining aesthetic durability, pollutant degradation, and self-cleaning properties, these coatings meet the dual demands of technical performance and sustainability, which are increasingly critical in the face of rapid urbanization and climate change.

From a technical perspective, TiO_2 coatings exhibit superior durability when compared to conventional systems, preserving façade reflectance and functionality for longer periods and reducing the need for frequent maintenance interventions. Their self-cleaning effect, driven by heterogeneous photocatalysis, not only maintains the visual quality of façades but also contributes to reducing the accumulation of organic and inorganic pollutants on exposed surfaces.

From an environmental standpoint, the study confirmed that TiO_2 coatings are capable of reducing NO_x and VOC concentrations in urban environments, directly improving air quality in densely populated areas. This benefit extends beyond

individual buildings, generating collective impacts that reinforce the role of the construction industry as an agent of socio-environmental transformation. Life Cycle Assessment (LCA) further demonstrated significant reductions in water consumption and CO₂ emissions associated with façade maintenance, strengthening the global relevance of this technology for environmental certification systems and climate goals.

From an economic perspective, although the initial application costs of photocatalytic coatings are higher than conventional alternatives, their total lifecycle costs are significantly lower. Savings stem from reduced façade cleaning frequency, diminished use of chemical agents, and enhanced real estate value due to the integration of innovative and sustainable technologies.

Nevertheless, some limitations should be acknowledged. The efficiency of photocatalytic reactions depends on UV radiation, which may affect performance in regions with low solar incidence. Furthermore, the long-term durability of photocatalytic activity over multiple decades still requires expanded field validation. In addition, the large-scale production and application of these coatings demand cost optimization and regulatory incentives to accelerate adoption.

Despite these challenges, the prospects for widespread application are promising. Photocatalytic coatings can be effectively applied to residential, commercial, and institutional buildings, both in new construction and in retrofitting projects. By integrating technical, economic, and environmental benefits, TiO₂-based coatings position themselves as one of the most consistent and scalable solutions for promoting cleaner, more resilient, and sustainable cities.

Finally, future research should expand applied testing in diverse climatic conditions and foster public policies and regulatory frameworks that support their dissemination. In doing so, the construction sector can make a meaningful contribution to the United Nations Sustainable Development Goals (SDGs), particularly those related to sustainable cities, responsible consumption, and climate action.

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