

## PHOTOCATALYTIC SELF-CLEANING FACADES IN ARCHITECTURAL DESIGN

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**Abstract.** *Sustainable and affordable technologies are an important aspect of environment and energy efficiency. Environmental pollution in urban areas is one of the causes for poor air quality. Gaseous emissions from daily traffic are continuously increasing often exceeding the allowable concentration in the atmosphere. The development of self cleaning materials- photocatalytic building materials- particularly when applied to facades, can contribute to providing the clean the air and to improvement of sustainability levels. They represents one of the most promising solutions for reducing air pollutant concentrations in urban areas, proving to be really effective and showing a real eco-sustainable value. The paper explains the mechanism of self-cleaning of façades, their types in architectural design and the importance of their application.*

**Key words:** *facades, self-cleaning, titanium dioxide, photocatalysis, glass, concrete, ceramics, architectural design*

### 1. INTRODUCTION

The air in the cities is polluted by nitrogen dioxide of vehicular exhaust and industrial emission. They cause respiratory problems and damage buildings. These problems cannot be handled even if car-free zones are created and environmental protection strategies introduced [1]. Normally, facades are cleaned twice a year using traditional methods. These methods provide a temporary solution and the building surfaces progressively become unsightly again. Soon, re-cleaning is necessary, and eventually refinishing due to the deteriorating effects of ultraviolet rays [2].

The use of environmental and sustainable green technologies is not simply a trend, but a necessity, which is increasingly important because of irresponsible attitudes of the past .

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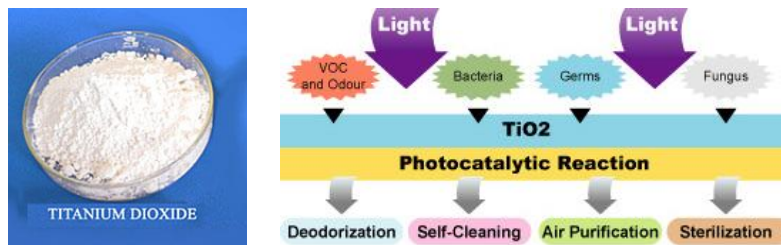
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The goal should be set of not only saving the environment through a responsible use of natural resources, but also through the consequent use of green technologies, thus preserving the resources for future generations [3]. For the above reasons, architects and environmental scientists have been teaming up to address an interesting question: is it possible and economically feasible to design and construct buildings that can passively clean smoggy urban air? [4].

As a solution to the above problem, the ever important concepts, are depollution and photocatalysis [4, 5]. They are rapidly entering the vocabulary of designers and builders around the world. A major international research consortium – the Photocatalytic Innovative Coverings Applications for Depollution Assessment (PICADA) – is documenting the performance of photocatalysts [2,6].

Depollution is the opposite of pollution and means removal of contaminants and impurities from the environment. The newest tool for achieving depollution is a photocatalyst, a material that uses solar energy to accelerate chemical reactions without being consumed or depleted in the process [7]. Photocatalyst accelerates the oxidation process in the atmosphere and decomposes any air borne toxic organic matter. Titanium dioxide, a photocatalyst, also known as titania, is the naturally occurring oxide of titanium, whose chemical formula is  $\text{TiO}_2$ , figure 1 a). Titanium Dioxide is considered a safe substance and harmless to humans. Using energy from light, Titanium Dioxide creates two oxidation reactants: hydroxyl radicals and a superoxide which decomposes toxic substance by oxidation [8].



**Fig. 1** a). Titanium dioxide [9] , b) Photocatalytic reaction[10]

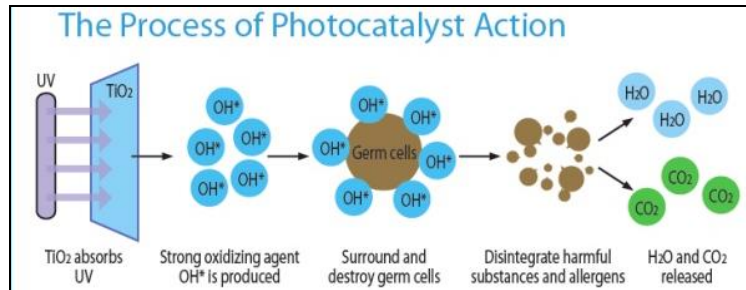
Oxidative decomposition means that if titanium oxide is exposed to light, organic substances on its surface will be broken down by oxidation, eventually forming carbon dioxide and water. This has applications in fields such as deodorization, elimination of volatile organic compounds (VOCs), elimination of soiling, antibacterial action and sterilization [3], figure 1 b). Photocatalyst has the following advantages over any current air and water purification technologies: destruction of pollutants rather than a simple transfer on a substrate, degradation of pollutants at ambient thermohygro-metric conditions and efficient energy consumption [11, 12].

## 2. PHOTOCATALYTIC SELF CLEANING FAÇADES

Photocatalyst treatment provides a long-term, cost-effective solution for facades maintenance while enhancing surface longevity. Once applied, it maintains the building's immaculate appearance with the self-cleaning cycle, figure 2. The treatment also protects

the surface of the building from mildew, dirt, oil residue and other pollutants. Photocatalyst architectural facades have the following properties:

1. Antistatic – Dust particles are no longer attracted to the surface.
2. Decomposition – Strong oxidizing effect to decompose hydrocarbon and any organic growth.
3. Hydrophilicity – Hydrophilic surface. Any dust or contaminant can be easily washed off by rainfall [10,13].



**Fig. 2** Photocatalytic self-cleaning cycle [14]

The photocatalytic process of self-cleaning of facades progresses in the following manner: When a compound (either an organic soil or a pollutant) is present on the surface of a TiO<sub>2</sub>-containing covering, it can be degraded by redox reactions involving highly reactive transient species, thanks to the activation of TiO<sub>2</sub> in the presence of UV light in the appropriate region. Then, the degradation products are either stored in the covering or washed off the surface by rain water.

This offers a great interest as, when the redox reactions are complete, organics yield carbon dioxide and inorganics, nitrogen oxides are oxidized into nitrate ions, and ozone is decomposed into oxygen. Simultaneously, visible deposits due to soiling can become gradually transparent as a result of these photocatalytic transformations. Thus, these innovative coverings can contribute to keep urban constructions clean as well as to reduce atmospheric pollution generated by the road traffic and industrial activities [15].

### 2.1. Self-cleaning glass facades

Self-cleaning glass is a specific type of glass with a surface which keeps itself free of dirt and grime through photocatalytic decomposition. A nanometer-scale coating of titanium dioxide (10-25 nm) on the outer surface of the glass introduces two mechanisms which give it the self-cleaning property. Harsh chemicals that are used to clean normal glass are usually washed off into the soil and contaminate it, figure 3 a). The use of self-cleaning glass eliminates this environmental hazard.

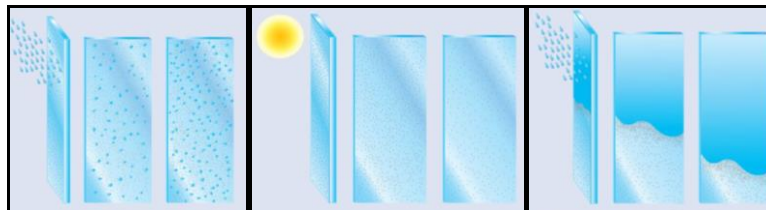
Self-cleaning glass cleans itself in two stages. The first stage is called photo-catalysis, figure 3 b), which is the action of light on the surface of the glass to basically chomp away or eat the dirt on the surface. The next is a process known as hydrophilicity, figure 3 c). This ensures that any water that falls on the surface forms sheets and washes away dirt uniformly. The glass spreads the water evenly over its surface, without forming droplets. Only a small amount of sunlight is required to activate the coating, which ensures that

self-cleaning property will function even on cloudy days. A simple rinse with water during dry spells will help keep the surface clean [16].

The performance of self-cleaning glass can vary depending on the environment and the location of the glass. Optimum performance is obtained when the glass is installed in a vertical position, and receives maximum exposure to direct sunshine and rain. The other factors in play are: the type of dirt, the amount of dirt, total exposure to light and rain and the inclination of the installation.

Self-cleaning glass has numerous advantages in comparison with normal glass. It requires less frequent cleaning; in addition a façade stays cleaner for longer periods of time. Cleaning itself is easier and costs are reduced. Due to hydrophilic coat, the vision is always clear through the façade with neutrality and transparency the same as that of normal glass.

One of the most famous manufacturers of this type of glass is the Saint Gobain company of France, which developed its line of BIOCLEAR glass. This glass has a self-cleaning property, however, there is an improved variant which offers an option of prevention of space overheating and glare reduction. This line of products is called SGG BIOCLEAR Cool-Lite [17].



**Fig. 3** a) Normal Glass- Dirty water marks and grime gather on the window. [17]  
b) Step 1: Photocatalysis [17] c) Step 2: Hydrophilic Action [17]

## 2.2. Examples - Buildings with self-cleaning glass

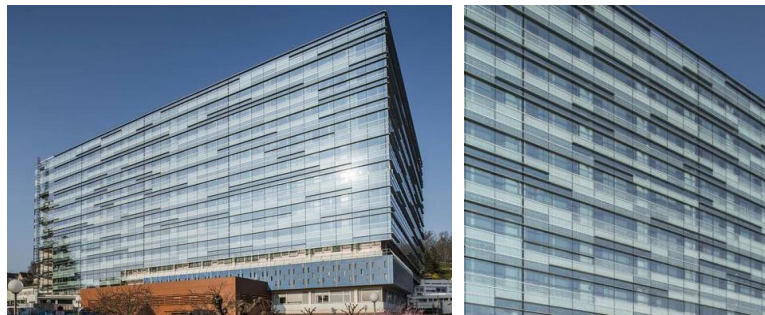
The Infoscore office building, designed by architect Herbert Basler is located in Baden-Baden, Germany, figure 4 a). The most impressive part of the building is 200 m<sup>2</sup> glass façade made of SGG BIOCLEAR glass. The façade is composed of the 2x4 m panels, figure 4 b). SGG BIOCLEAR glass was chosen for its self-cleaning effect due to the high level of soil pollution [18].



**Fig 4.** a) Infoscore office building, Baden-Baden, Germany [18]  
b) Infoscore office building, glass façade detail [19]

The five-storey extension of Infoscore offers office space for 400 employees. Cleaning of the associated glass facade would be difficult because it is not easily accessible and due to the high pollution load. The glass part of the façade is located on the rain-impact side and is mounted absolutely vertically. Due to its position, after heavy rainfall, soiling is washed away and the façade is clean again. Self-cleaning does not mean they do not absolutely require cleaning. Even glasses like SGG BIOCLEAN have to be cleaned from time to time, but considerably less often than conventional glass. The length of the cleaning intervals depends strongly on the angle of inclination of the glass surface. The steeper the angle, the longer the intervals.

Brive-la-Gaillarde hospital in France represents a very interesting example of façade reconstruction with an aim of improving its quality. The building was built in 1976, while the renovation process started in November 2012., figure 5 a). It was designed by the architectonic studio EMaa in cooperation with Manière & Mas and Technal design company. The concept was based on construction of a double ventilating façade using the most contemporary materials. The glass used for the external part of the façade was SGG BIOCLEAN Cool-Lite, figure 5 b).



**Fig. 5** a) Hospital Brive-la-Gaillarde after renovation [20]  
b) SGG Bioclean Coll-Lite used for the outer glass [21]

This building, which occupies the main artery of the Hospital Center, has its south-east and south-west façades modified by the addition of a double skin. This project was realized without interrupting the hospital operation. Renovation of these two façades improved the patient and staff comfort, in accordance with the standards of the Grenelle de l'environnement. It also improves the safety of the establishment, by providing emergency services accessibility to the twelve floors from the outside. The total height of the building is 39 meters.

The idea of renovation is a double facade ventilated on the twelve levels, with a thickness of one meter and bridges on all levels. The outer glass creates a thermal barrier that creates a buffer space along the building. This space is tempered in winter like a greenhouse and ventilated in summer thanks to high and low vents which accelerate the air inside by the chimney effect. The facade is self-cleaning (BIOCLEAN glazing) and it is necessary that rainwater trickles on the glasses for cleaning. For this, the profile of the sunshade is an inverted slope and brings the water along the facade. A gap between the facade and the bonnet of the sunshade allows the flow of rainwater [21].

### 2.3. Self-cleaning ceramic tiles facades

The HYDROTECT® technology, the Bios Self-Cleaning® ceramics in facings and ventilated walls provide important responses through their self-cleaning. In particular, Bios Self-Cleaning® contains titanium dioxide (TiO<sub>2</sub>). The self-cleaning property of Bios Self-Cleaning® is effective but it should be kept in mind that: they cannot remove all the stains, such as stains that stick to the facing quickly, massively and stubbornly, e.g. silicone sealants, they cannot remove rust or crystals and no self-cleaning process may take place without rain or exposure to UV rays.

Residential commission in Germany brought Daniel Libeskind back to Berlin for his first residential project in the city. The project, known as Saphire, located on a busy corner in the Mitte neighborhood in central Berlin, presented a design challenge, figure 6. The three-dimensional, geometric-patterned stoneware tile adorning the facade is another design signature. Designed by Daniel Libeskind for Casalgrande Padana, the panels are technologically engineered to self-clean and aid in air purification [22].

Of the 3,600 tiles supplied, only 500 were made in a standard production format. The remaining 3,100 tiles are custom shapes made using controlled linear and water jet cuts according to precise drawings. Additionally, every tile was specifically positioned to reflect the A or B sides of the pattern (the two positions of the tiles when rotated by 180 degrees). This specificity allowed the architects to control the overall patterning and reflective effects of the facade. The ventilated facade was assembled utilizing a standard anchorage system [23].

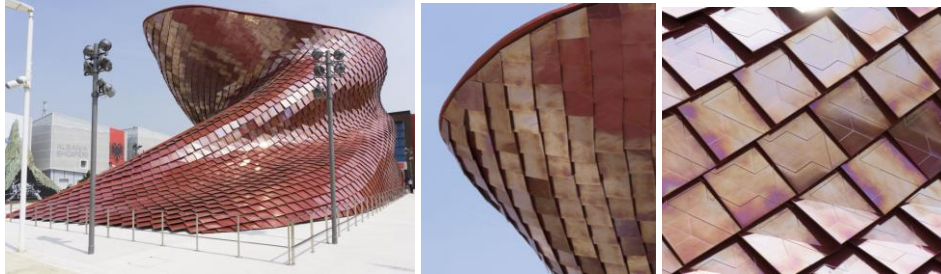


**Fig. 6** Daniel Libeskind - his first residential project in Berlin (© Hufton+Crow Photography) [22,23]

The concept for the Vanke Pavilion, situated on the southeast edge of the Lake Arena, figure 7, incorporates three ideas drawn from the Chinese culture related to food: the shi-tang, a traditional Chinese dining hall; the landscape, the fundamental element to life; and the dragon, which is metaphorically related to farming and sustenance. All three of these concepts are incorporated in the Vanke pavilion.

The Vanke pavilion is clad in more than 4,000 red metalized tiles that Libeskind designed with the Italian company Casalgrande Padana. The geometric ceramic panels not only create an expressive pattern that is evocative of a dragon-like skin, but they also possess highly sustainable self-cleaning and air purification properties. The three-dimensional surface is coated with a metallic coloration that changes as light and viewpoints shift. The tiles are installed with

a state-of-the-art cladding support system that gives a rhythmic pattern and mathematical form to an otherwise supple, twisting shape [24].

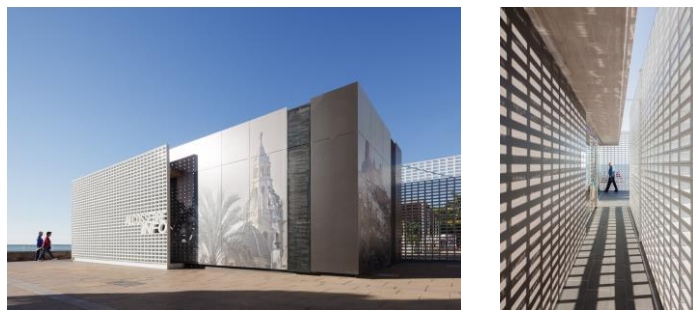


**Fig. 7** Vanke pavilion - Daniel Libeskind - the geometric ceramic panels [24].

#### 2.4. Self-cleaning porcelain tiles facades

Beaumont Tiles has laminated porcelain tiles with potential for innovation in architecture and interior design. Key features of the Coverlam porcelain rectified tiles include resistance to UV light, chemicals, wear, fire and frost; easy-to-clean surface preventing mould and bacteria; eco-friendly material using 2-3 times less raw quarry materials than any other type of porcelain tile, and fired in a hybrid kiln (gas and electricity) requiring less energy to produce; recyclable material; and Hydrotec treatment (titanium dioxide coating) giving self-cleaning, antibacterial and odour-elimination properties [25].

Coverlam porcelain rectified tiles are ideal for ventilated facades, as well as smaller buildings and private houses. One of the most interesting projects is located in the coastal town of Alcossebre. It is a part of a Strategic Plan for Tourism Development in agreement with the Polytechnic University of Valencia and whose purpose is to promote tourism in the area through small spaces, buildings and activities of design, figure 8. Three different types of ceramics, with different thicknesses, formats, colors, finishes and applications are used. One of three pieces of ceramics used, Coverlam, is a laminated porcelain slab with 5mm thickness and 300x100cm size from Grespania. This piece is installed in a rainscreen and wall cladding [26].



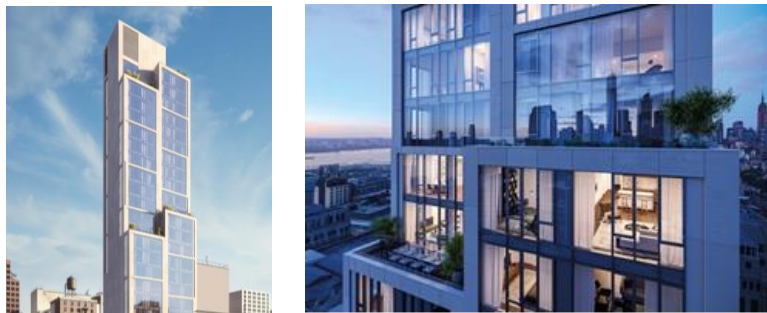
**Fig. 8** Tourist info pavilion in Alcossebre, Spain – H & C tiles [26].

### 2.5. Self-cleaning sintered stone tiles facades

Spanish hard surfaces company Neolith recently launched the collection of façade tile systems Skyline. The slabs are covered with Cincinnati, Ohio based surface treatment manufacturer Pureti's proprietary aqueous and titanium dioxide nanoparticle-based coating that creates self-cleaning and air purifying surfaces.

Made from 100 - percent natural raw materials such as granite minerals, silica, and natural oxides they can be installed as ventilated façades. Through sintering technology, the product undergoes exposure to extreme heat and pressure to create a nonporous, durable surface. Pureti credits two chemical processes that make the coating technology possible: photocatalysis and superhydrophilicity. Superhydrophilicity is initiated by contact with water, as in the case of rain or precipitation. As the water expands over the treated surface, the thin film of titanium dioxide nanoparticles formed from photocatalysis washes away dirt particles off the façade, reducing the need for frequent cleaning of the building's exterior.

Luxury tower in Manhattan's Hudson Square, 570 Broome, 25-story, has a façade which cleans the air, figure 9 a) and figure 9 b). The building is clad in 2,000 square meters of Neolith paneling - a material comprised of raw minerals that have undergone high heat and pressure to mimic the appearance of natural stone - that is coated with a titanium dioxide nanoparticle-based treatment called Pureti. The building is situated next to New York's traffic-ridden Holland Tunnel, making its presence even more welcome in the area [27].



**Fig. 9** a) The rendering of 570 Broome in New York City [28]

b) 570 Broome in New York City - Neolith paneling with Pureti coat [27]

### 2.5. Self-cleaning concrete facades

New photocatalytic cements can be used to produce concrete and plaster products that save on maintenance costs while they ensure a cleaner environment. Italcementi tests have demonstrated that a road paved with concrete made with the photocatalytic cement can reduce NOX levels by 20 to 80%, depending on atmospheric conditions. A building with photocatalytic precast concrete cladding can do the same. Italcementi is one of the most famous companies that produce and develop photocatalytic cements.

TX Active®, TX Aria and TX Aria are products with photocatalytic properties, developed by Italcementi.

The products containing TX Active® are able to abate air noxious organic and inorganic substances and they preserve over time the aesthetic quality of the finished products. TX



Active® is an environmental friendly product for mortars, paints, precast elements and pavements plasters.

Concrete containing TX Arca will resist most organic and inorganic pollutants that gather on the surface causing discoloration. TX Arca with its self-cleaning effect, is the cement complying with the requirements set forth in European Standard EN 197/1 and is specifically designed for building prestigious architectural structures.

In addition to the self cleaning effect, concrete made with this TX Aria cement, will remove significant amounts of environmental pollutants (Nitrogen Oxides, Sulfur Oxides, Volatile Organic Compounds, Ammonia, Carbon Monoxide, Organic chlorides, aldehydes, polycondensated aromatics) [29].

About 20 years ago, the United Nations identified Mexico City as the single most polluted city on the planet. In 1992, Mexico City's levels of sulphur dioxide, suspended particulate matter, carbon monoxide, ozone, lead, and nitrogen dioxide all exceeded the World Health Organization's health protection guidelines. The Torre de Especialidades is an addition to the Hospital Manuel Gea Gonzales, located in the southern Tlalpan neighborhood of Mexico City. The tower was built as part of an ongoing \$20 billion government project to improve the city's health infrastructure.

The hospital building is shielded by an eye-catching 100-yard-long façade made with special tiles called "proSolve370e," that have air-scrubbing abilities. The mass-produced tiles, created by Berlin-based architecture firm Elegant Embellishments, are coated with titanium dioxide. The architects hope is that the building can counteract the impact of about 8,750 of all cars driven in Mexico City and provide a slightly fresher air in the hospital's immediate area. In addition, the innovative lattice-like design of the tile shapes "slow wind speeds and create turbulence, for better distribution of pollutants across the active surfaces, figure 10.



**Fig. 10** The hospital building called the Torre de Especialidades, Mexico City [30, 31].

The omni-directionality of the quasicrystalline geometry is especially suitable to catch things from all directions. The façade produces shadows in the inside of the building, helping to keep it fresh and cool. That way the amount of air conditioning needed to cool it is kept at its lowest possible level, helping save electric energy [30,31].

The pavilion, the city of Milan, Italy for Expo 2015 consists of the permanent building Palazzo Italia (6 levels, built area 14,398 sqm) includes: exhibition spaces, auditorium, delegations spaces, offices, events spaces, meeting spaces, restaurant. The building is designed in a sustainable way thanks to the contribution of photovoltaic glass in the roof and the 9,000 square meters of photocatalytic concrete that has titanium dioxide for the

branched facade, figure 11 a) and 11 b). For the design of this "skin" Nemesi has created a unique and original geometric texture that evokes the intertwining random branches. The full external façade of Palazzo Italia is clad in over 700 i.active BIODYNAMIC panels realized by Styl-Comp with Italcementi's patented TX Active technology [32].



**Fig. 11** a) The pavilion, the city of Milan, Italy for Expo 2015 [32],

b) The pavilion, Milan, Italy for Expo 2015 –the part of the photocatalytic façade [32].

One of the most famous buildings with photocatalitics concrete is the Jubilee Church (also known as the Dives in Misericordia) in Rome, completed in 2003. The soaring structure was designed by the award-winning international architectural firm of Richard Meier & Partners Architects LLP. It is a composition of 256 precast, post-tensioned concrete elements assembled into curved white “sails” that rise 85 feet into the sky, figure 12 [33].



**Fig. 12** Via di Tor Tre Teste, Rome, Italy left [33], right [34].

## CONCLUSIONS

The constant evolution of facade systems is leading to the use of high performance technology. There is a wide range of innovation enabled by technologies for processing materials and integrating currently available materials for creation of new generation facades. The PICADA Project has permitted the development of a full range of photocatalytic facade coatings that display both de-soiling and de-polluting properties, thanks to the introduction of nano-particles of anatase titanium dioxide. Titanium dioxide ( $\text{TiO}_2$ ) is highly resistant to

environmental pollution, marine environments, performs well in even severely aggressive environments. These properties make titanium a material well suited for architectural applications for ecological self-cleaning facades. The said performances have been demonstrated through an extensive laboratory testing programme as well as outdoor and indoor field trials [15].

The world is increasingly seeking to design buildings with photocatalytic self-cleaning facades of various materials such as: glass, ceramic, artificial stone and photocatalytic concrete. The permanent application of products such as photocatalytic coatings, the level of pollution of the environment would be significantly reduced. A wide range of products with these abilities offers a solution for a variety of building types and facade shapes. As it is presented in the paper, the choice of material is no longer an obstacle in the struggle for a healthier and cleaner environment.

It is concluded that structures with self-cleaning facades significantly influence the improvement of air quality in urban areas, therefore, the quality of life itself.

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## FOTOKATALITIČKE SAMOČISTEĆE FASADE U ARHITEKTONSKOM PROJEKTOVANJU

*Održive i pristupačne tehnologije su važan aspekt energetske efikasnosti i očuvanja životne sredine. Zagađenje životne sredine je jedan od uzroka lošeg kvaliteta vazduha. Emisije gasova svakodnevnog saobraćaja se neprestano povećavaju, i često prevazilaze dozvoljene koncentracije u atmosferi. Razvoj samočišćenih materijala - fotokatalitičkih građevinskih materijala, pogotovo kada se primene na fasade mogu doprineti obezbeđenju čistog vazduha i poboljšanja održivosti. Oni predstavljaju rešenja za smanjenje koncentracija zagađenja u urbanim područjima koji najviše obećavaju, pokazujući efikasnost i pravu vrednost u smislu eko-održivosti. Rad objašnjava mehanizam samočišćenja fasada, njihove tipove u arhitektonskom projektovanju i važnost njihove primene.*

*Ključne reči: fasade, samočišćenje, titanijum dioksid, fotokataliza, staklo, beton, keramika, arhitektonsko projektovanje.*