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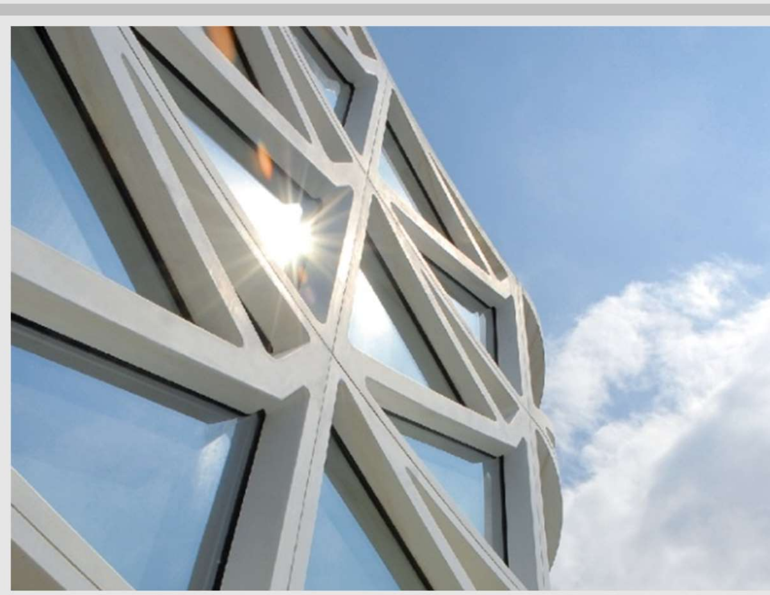
PHOTOCATALYTIC COMMUNICATION KIT

The role of photocatalytic cement-based products as sustainable solutions



INTRODUCTION

The technology of TiO_2 photocatalysis applied to the buildings materials has become very attractive with many social and environmental advantages. Application of photocatalysis to building envelopes, road facilities and tunnels reduces air pollution, contributes to reduce maintenance costs and enhances the control of Urban Heat Island effect in densely populated cities or heavy traffic areas as well.
A particularly interesting aspect of TiO_2-cement composites is the synergy between the cement and TiO_2 that makes **cement an ideal substrate** for environmental photocatalysis.
Literature research and internal experimental results clearly demonstrate that cementitious materials containing titanium dioxide not only reduce soiling rate in the surface but can also participate to the abatement of air pollutants, especially NOx,in outdoor and indoor urban atmospheres.
It is important to underline that the photocatalytic activity provided by TiO_2 cement-based materials is strongly influenced by surface finish, active principle content, UV irradiation level and environmental conditions (i.e. relative humidity, wind); to improve oxidative degradation activity, in indoor applications it is essential to use UV light sources.

PHOTOCATALYSIS: HOW DOES IT WORK?

The contribution of photocatalysis becomes more and more important given the increase of the environmental issues such as climate changes, scarcity of energy and greenhouse gases emissions, which request new environmentally beneficial technologies.

A photocatalyst is a semiconducting substance which can be chemically activated by light radiation that results in oxidation-reduction (redox) reaction, i.e., it has a photocatalysis action or photoactivity. Photocatalysis is similar to the photosynthesis in plants in the mechanism, in which chlorophyll acts as a catalyst to produce oxygen from carbon dioxide and water. Chlorophyll is a very powerful photocatalyst. The photocatalyst in the photocatalysis process corresponds to the chlorophyll in the photosynthesis process.

Many investigations to discover effective photocatalysts have been conducted up to the present time. However, titanium dioxide (TiO_2) with a crystal structure of anatase type has so far been found to be the most effective photocatalyst enabling industrial use.

In the titanium dioxide photocatalyst, when activated by solar light or ultraviolet radiation, the following two phenomena and their effects are simultaneously induced on its surfaces as seen in Fig. 1.

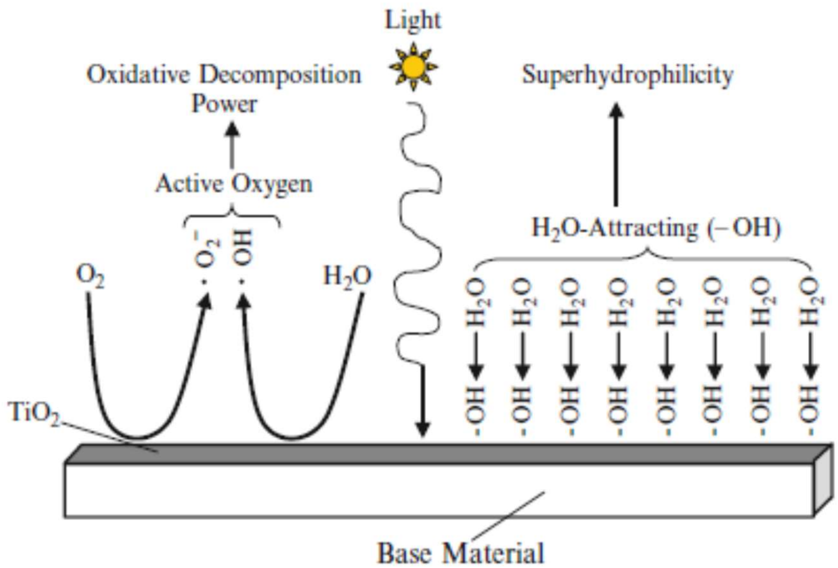


Fig.1 - Two phenomena simultaneously induced by TiO_2 photocatalysis

1. Photocatalytic oxidative decomposition power due to active oxygen consisting of hydroxyl radicals (·OH) and superoxide ions (·O2 −) – Strong decomposition power effect
2. Photoinduced superhydrophilicity due to water-attracting hydroxyl groups (−OH) – High water-wettability effect
3.

Such photocatalysis can also be induced by slight ultraviolet radiation due to fluorescent lights, etc.

PHOTOCATALYTIC CEMENTS

The ideal support material would be low cost, mechanically durable, UV stable, and highly resistant to photocatalytic oxidation; cement-based materials meet all these requirements perfectly.

Cementitious materials with TiO_2 photocatalyst develop the **major performance** or functions as shown in Fig. 2, based on both effects of strong decomposition power and high water wettability.

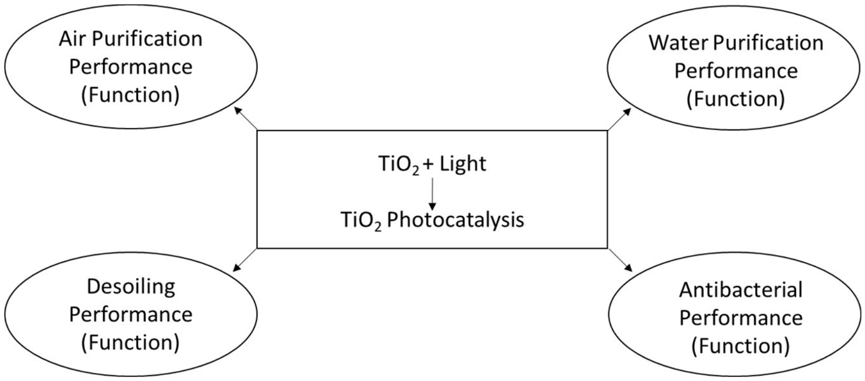


Fig.2 - Major performance or functions developed by TiO2 photocatalysis in cementitious materials with TiO_2 photocatalyst

For the past 25 years, the technology of TiO_2 photocatalyst has progressed rapidly, and become very attractive in the development of construction materials with de-soiling and air purification . As a result, various construction materials are being developed by utilizing the TiO_2 photocatalysts. Since the TiO_2 is added in the bulk of the structure, the concrete technology and final mechanical properties of products do not change: for these purposes, both white and grey cements can be used, without any particular problems. Organic admixtures for concrete and other cement-based materials must be properly selected, to avoid possible reduction or interferences on the photocatalytic activity of the products.

A broad list of possible applications of photocatalytic cement-based materials can be summarized as follows (in terms of photocatalytic products, wide surface and low thickness solutions are advantageous):

horizontal applications	vertical applications	tunnels
• concrete pavements • paving blocks and paving plates • coating systems for pavements and roads (white toppings, self-levelling mortars) • roofing tiles • roofing panels • cement-based tiles	• indoor and outdoor paints • finishing coatings, plasters and other final rendering cement-based materials • permanent formworks • masonry blocks • sound-absorbing elements for buildings and roof applications • traffic divider elements • street furniture • retaining fair-faced elements • precast panels	• paints and renderings • concrete panels • concrete pavements • ultrathin white toppings

Urban Heat Island effect (UHI)

The Urban Heat Island (UHI) is a global issue that threatens the operation and **habitability of cities and urban environments**.

The concept of the UHI has been well researched and documented; however, the understanding of the topic is quite limited. The heat island effect is characterised by the development of noticeably higher temperatures in cities compared with the countryside that directly surrounds them. Initial studies conducted by the World Meteorological Organisation and Oke revealed that the UHI effect can increase air temperature in an urban city by between 2 and 8 °C.

As evidenced in Fig.3, recent studies illustrate that a more accurate range is **between 5 and 15°C**. The heat island effect arises due to the changing nature of our cities, and is the result of a reduction in vegetation and evapotranspiration, a higher prevalence of dark surfaces, and increased anthropogenic heat production.

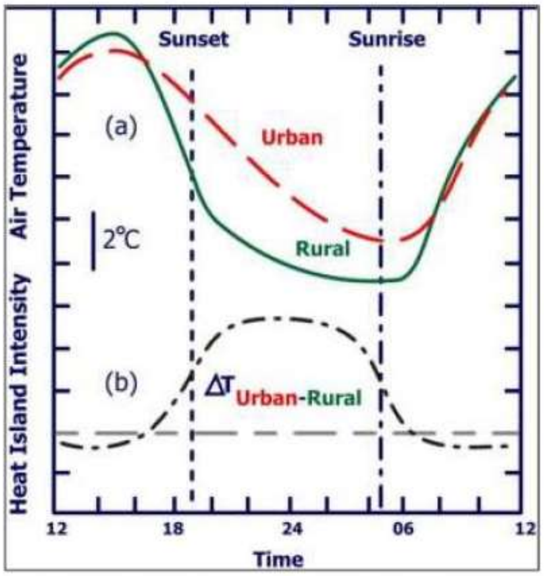


Fig.3 - Simulation of temperature of urban and rural areas during day and night

Therefore, the existing surface conditions of an urban area will directly impact on the chosen UHI mitigation strategies. Over 60% of an urban surface can be covered by hard, man-made, heatabsorbent surfaces. Knowledge of the urban fabric and surface conditions of a city is important in order to explore the effects of possible UHI mitigation measures.

The UHI can be illustrated by drawing a curve from one side of a city to the other (Figure 4.), mapping graphically the temperature change from the rural to the urban environment and back to the rural environment.

The “island” would be represented by the large spike in the centre of the graph, which generally mimics the outline of the structures within the urban area, and is bound by the cliffs either side that mark the urban and rural boundary.

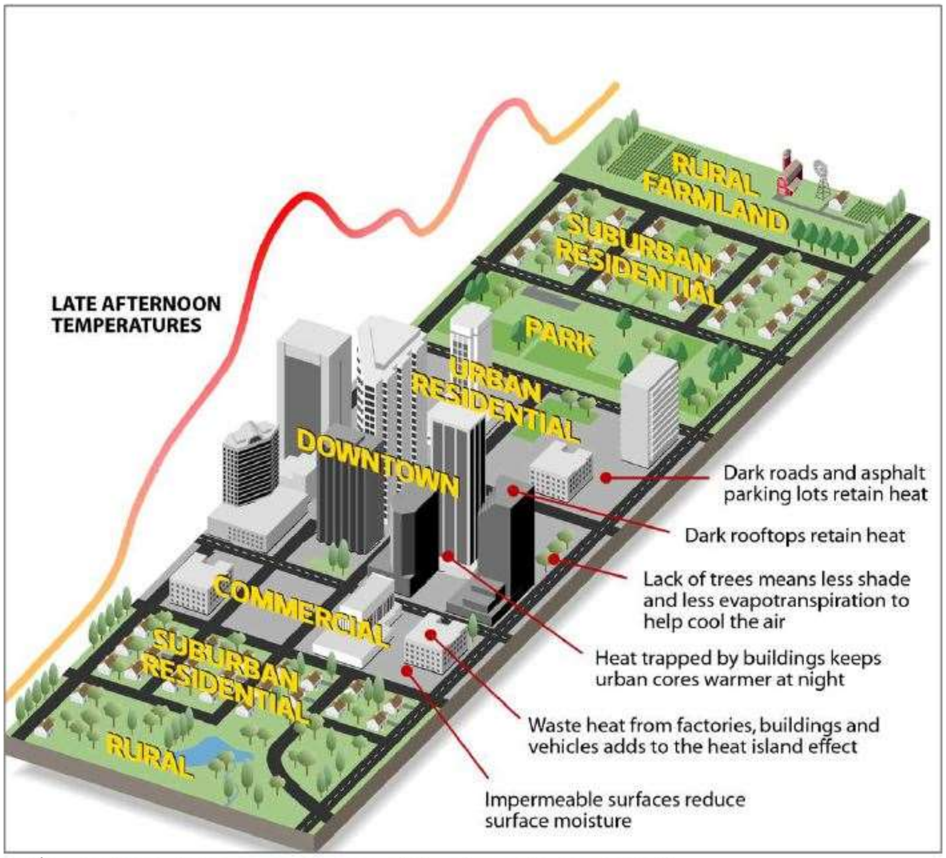


Fig.4 – Schematic view of temperature profile across an urban heat island

By illustrating the UHI in this way, it is easy to recognise the profound increased temperature difference to which our cities are exposed. It is important that strategies are developed for adapting to, and **mitigating** the adverse environmental effects of UHIs. In most research to date, the primary solution to the UHI has been replacing dark materials with light-coloured materials for greater solar reflectivity.

The most significant cause of the UHI is **urbanisation**. The constant increase in hard and heat absorbing surfaces, the density of our cities, and the reduction in natural vegetation are the main contributors to the heat island effect.

Increase in heating and cooling energy needs technological developments within society contribute to the UHI effect through increased heating and cooling. The most significant are air conditioning systems, which, although effective for increasing human comfort, inherently generate a greater level of heat.

Urban geometry can greatly affect the efficacy of UHI mitigation methods, particularly reflective pavements. The urban canyon (UC) is a descriptive term for roads and pathways surrounded by the buildings, walls and roofs of an urban environment. This combination of roads and buildings essentially creates canyon-like structures that are subjected to many reflections. The geometry of an urban canyon will affect the magnitude of radiation reaching street level and escaping back into the atmosphere. The urban canyon of tall buildings and narrow streets trap heat, and prevent air circulation. The urban geometry is also the greatest man made influence on wind flow characteristics through an urban zone. Therefore, understanding the holistic effect of UHI mitigation measures on the entire urban street environment is an important point of the current research.

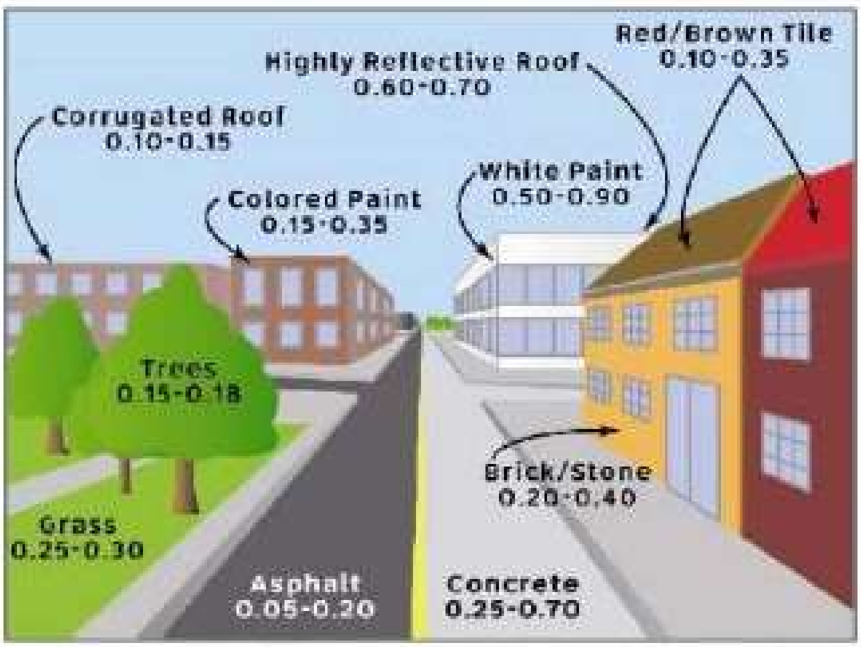


Fig.5 – Illustration of urban surfaces with different albedo levels

Highly reflective materials to solar radiation when used in the urban environment present a significantly lower surface temperature and contribute to reducing the sensible heat released in the atmosphere and mitigating the urban heat island.

The **reflectivity** of a pavement structure and the percentage of associated solar radiation absorbed are also known as the albedo. In general, lighter coloured materials, or smoother surfaced pavements have a higher albedo, and, hence, reflect, rather than absorb, more solar radiation.

In contrast to the increasing albedo of asphalt, the albedo of concrete decreases over time, as dirt, tyre wear and exposure darken the pavement. Research in this field is important to determine the economy of using reflective coatings embodying desoiling properties, such as TiO_2-based materials.

Brightness and Colour

Discoloration, appearances of stains, accelerated wear, fouling due to soot particles and corrosion or erosion caused by acids are some problems caused by the accumulation of pollutants on the building envelope. Due to these shells being constantly in contact with degradation agents and the direct incidence of ultraviolet radiation, coatings tend to become more opaque over time affecting their colour and reflectance characteristics.
Adding a photocatalyst to external surfaces of buildings or coatings of facades containing a photocatalyst, could provide a surface with hydrophilic characteristics and would certainly decrease the degree of dirtiness on these surfaces, which could be washed in the rain, or alternatively sprayed with water occasionally, thus promoting a "**desoiling effect**".

Since the rate of the black carbon removal is much faster than the rate of deposition, a TiO_2 containing cementitious material may be able to maintain **the high solar reflectance** when exposed to continuous soiling by emissions of automobile traffic, industrial and domestic combustion, provided that the surface is exposed to an adequate solar irradiation. This allows to maintain the solar reflectance over time: the capacity of the photocatalytic coating to reduce the heat gain through building envelope, indicating the reduction of cooling energy demand can be assessed. In fact this may postpone the arrival of peak temperature, increase indoor thermal comfort, and shorten the cooling period.

The use of high spectral reflectance building surfaces is one of the main solution to reduce the UHI effects.

For these reasons, the implementation of highly reflective coatings roofs and paved areas, in a warm and humid climate area, could be massively handled with promising local and global benefits. Indicatively, increasing the albedo of a 1 m2 area by 0.01 results in a global temperature reduction of 3×10–15°C and offsets emission of 7 kg CO_2.
The social and environmental advantages of increasing the reflectivity of roofs and pavements inside cities and in interurban roads have been evidenced. Adopting sustainable TiO2-based building materials for roofs and pavements represent a strong contributory factor to the **mitigation of UHI effect in cities**. Moreover, thanks to the desoiling effect, the surface reflectivity levels can be maintained for a significantly longer time.
Indirect building energy saving depends on other specific variables too, e.g. buildings constructive characteristics and cooling/heating systems; however, real and simulated case studies analysed in literature show positive effects of such applications in terms of surface temperature reduction.

Increasing urban albedo in a 10% would allow saving more than 1 billion Euros only in the United States thanks to direct effects and also to the mitigation of urban heat islands. Additionally, its influence on global temperature could slow down global warming which, besides being a positive action itself, would determine significant equivalent economic saving during the next years.

CLEAN AIR: HOW TO HELP OUR CITIES

Notwithstanding “clean air” is considered a basic requirement for human health and well-being, air pollution remains a meaningful threat to health worldwide. In the atmosphere, the presence of substances that naturally do not occur, even at very low concentration, has a noxious effect on human beings, animals, vegetation and materials.
Air pollution is a sort of **“silent and invisible killer”**, i.e. ranking the fourth one in the world. According to the estimates by the World Health Organization (WHO), over 6,000,000 deaths in 2016 – as a result especially of lung cancer, stroke, heart disease – are attributable to ambient air pollution, of which more than 67% concentrated in South-East Asia and Western Pacific Regions.

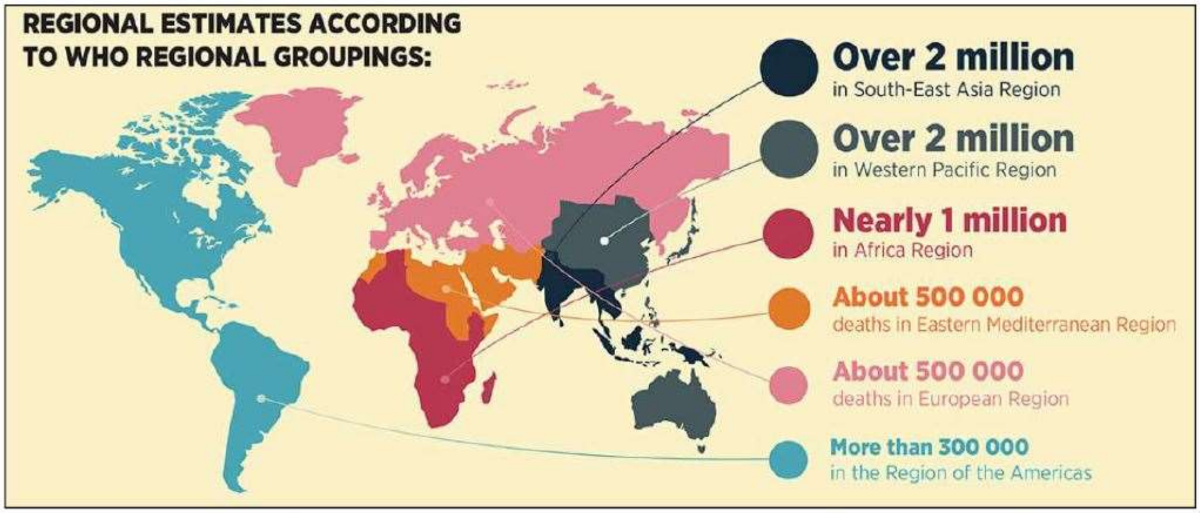


Fig.6 – Worldwide overview of premature deaths, 2016 (source: WHO)

Air quality may become increasingly worse with the rapidly expanding urbanization: currently, more than half the world’s population live in cities, and it is expected to reach two thirds by 2050.
As more people move from rural areas to cities, there will be more vehicles on the roads, more traffic congestion hotspots near homes and workplaces, and less green areas, resulting in more polluted cities and towns.

TREES AND PHOTOCATALYTIC PRODUCTS

Street trees can improve aspects of city life like air quality, biodiversity, and various beneficial health outcomes. Urban environments are increasingly suffering from bad air quality and smog, and planting trees remains one of the cheapest and most effective ways of drawing excess carbon dioxide from the atmosphere: in fact, trees in street proximity absorb 9 times more pollutants than more distant trees, converting harmful gasses back into oxygen. **Street trees can improve air quality** by intercepting and absorbing particulate pollution at street level, reducing urban ozone levels by lowering air temperatures through transpiration, removing air pollutants through surface deposition, and reducing building temperatures.

As far as the pollutants, street trees remove ozone, particulate matter less than 10 µm, nitrogen dioxide (NO2), sulphur dioxide (SO2) and carbon monoxide (CO). For example, the average quantity of NOx removed by an urban street tree, according to Nowak's theory, is equal to 75 g/y.
On the basis of hundreds of results – achieved on different typologies of photocatalytic products (e.g. TX and i.active cements, TioCem, coating mortars, paving block, concrete roof tiles, etc.) – it is possible to assume a potential NOx degradation rate between 6 and 7.5 g /(m2·y) that, in real operating conditions, may be influenced by UV light exposition, relative humidity and wind conditions (direction, speed).

This means that **the Equivalent Removal Factor (EFR) between an urban tree and a photocatalytic cement-based surface** is between 10.0 and 12.5, namely 10 to 12.5 square metres of a photocatalytic product correspond to 1 tree, or 100 square metres of photocatalytically active surface amounts to 8-10 trees.

Urban street tree	Photocatalytic surface		Photocatalytic surface	Urban street tree
10	(100 – 125) m^2		10 m^2	0.8 – 1
1,000	(10,000 – 12,500) m^2		1,000 m^2	80 – 100
5,000	(50,000 – 62,500) m^2		5,000 m^2	400 – 500

Tab.1 – equivalence "trees <-> photocatalytic cement-based surfaces"

If we consider, for example, the new HeidelbergCement Headquarter under construction – whose depolluting surfaces completed with **white photocatalytic concrete** should be **about 6,000 m2** – this corresponds potentially to an **equivalent** number of **480-600 urban street trees**.

Fig.7 – HeidelbergCement new Headquarter, rendering

VEHICLE EMISSIONS ABATED BY PHOTOCATALYTIC PRODUCTS

As was pointed out previously, the quantity of NOx potentially removed by a photocatalytic cement-based material is between 6 and 7.5 g/(m2.y), while our assumptions have resulted in 343 g for a Euro 6 PI (gasoline) vehicle and 458 g for a Euro 6 CI (diesel) vehicle, as NOx yearly emissions.

This means that 46-57 square metres and 61-76 square metres of photocatalytic cement-based
surface could offset, respectively, the yearly emissions of a gasoline (table 2) and a diesel (table 3) vehicle.

Gasoline car (Euro 6)	Photocatalytic surface (needed to eliminate the corresponding emissions)
1	(46 – 57) m^2
10	(460 – 570) m^2
1,000	(46,000 – 57,000) m^2

Tab.2 – number of Gasoline car that can be “neutralized” by photocatalytic surfaces

Diesel car (Euro 6)	Photocatalytic surface (needed to eliminate the corresponding emissions)
1	(61 – 76) m^2
10	(610 – 760) m^2
1,000	(61,000 – 76,000) m^2

Tab.3 – number of Diesel car that can be “neutralized” by photocatalytic surfaces

Alternatively, vice versa:

Photocatalytic surface	Gasoline car (Euro 6)	Diesel car (Euro 6)
1,000 m^2	18 – 22	13 – 16
10,000 m^2	175 – 217	132 – 164

Tab.4 – Photocatalytic surfaces areas to “neutralize” Euro 6 vehicles

Below, 2 cases to concretize the equivalence effect “photocatalytic concrete surface – number car equivalence”:

Case 1

Assumption: one lane of a **street made of photocatalytic cement-based paving blocks**, 1,000 m long and 2,5 m wide, for a resulting total surface equal to 2,500 m^2.

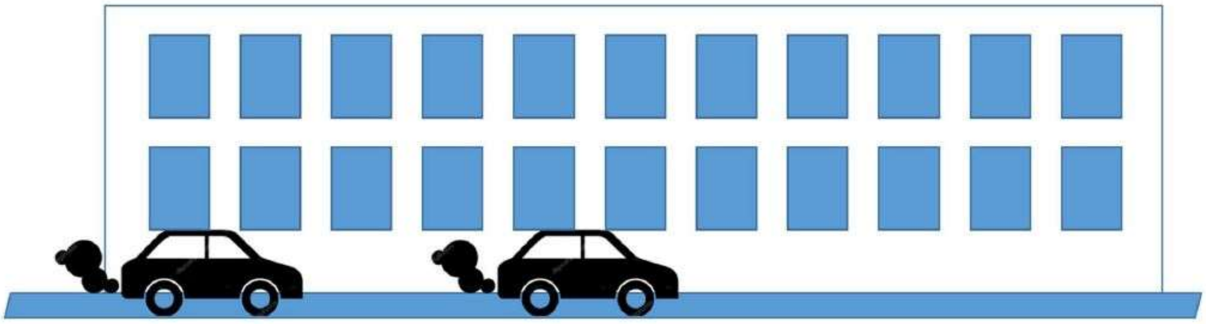
Result: this surface can abate (15 –18,8) kg NOx in one year.

If we consider that Euro 6 M gasoline vehicles release 343 g/y and the diesel ones 458 g/y, the 1 km photocatalytic lane may potentially abate the equivalent yearly traffic pollution of **nearly 45-55 Euro 6 M gasoline vehicles** or **35-40 Euro 6 M diesel vehicles.**

Case 2

Assumption: one depolluting area, i.e one building surrounded by a parking or streets. We can consider different surfaces installed: in this case, in a more restricted area, the amount of photocatalytic surfaces installed can be high.

Result: if we consider, once again, the new HeidelbergCement Headquarter under construction – whose depolluting surfaces completed with **white photocatalytic concrete should be nearly 6,000 m^2** –this corresponds to an annual NOx abatement between 36 and 45 kg.



This means that the resulting photocatalytic surface can potentially remove the equivalent yearly traffic pollution of nearly **105-130 Euro 6 M gasoline vehicles** or **80-100 Euro 6 M diesel vehicles**.

LONG LASTING FAÇADES AESTHETIC VALUE

What is expected by the i.active product range is the maintenance of colour brilliance and, in general, of “good conditions” after several years of service.

We have taken under observation several buildings in different conditions made for over 10 years where i.active photocatalytic range was applied, following this purposes:

- the aging status of different products in the photocatalytic range
- highlight good practices/critical issues related to construction and/or design aspects
- suggest good maintenance practices based on real experiences
- support an action of conscious promotion of i.active products to future jobsites.

The parameters to be considered are related both to the design phase and to the construction phase.

From the point of view of the **DESIGN PHASE**, three aspects can (sometimes, strongly) influence the quality of the surfaces of Architectural Projects:

- **SHAPE AND ORIENTATION**
- **(AESTHETIC) DETAILS**
- **MAINTENANCE**

Shape: horizontal and sloping surfaces collect more dirt than vertical surfaces.

Orientation: determines how different parts are affected by the weather patterns.

In the northern hemisphere, the northern façade of the building will be more humid and also the photocatalytic activity will be penalized (depending on the intensity of the solar radiation).

Details: one of the main reasons for damaging building facades is rainwater.

A careful design of the construction details makes it possible not to let the water flow on the facades or to make it flow in predefined paths.

There are a whole array of architectural design features that can be employed to **manage water flow**:

- horizontal projections could be used in order to shelter the wall below (much large overhangs are necessary at roof level) or to disperse the flow as evenly as possible over the surface

- surface texture: the more textured and porous the concrete surface, the greater the opportunity for detritus to collect on the surface and cause staining.
The rough surface is not in itself a criticality: the critical aspect is the porous surface.

- changes of plane can be useful to channel water flow over the surface and hence contribute to controlling the weathering of a façade. Obviously all concave or slightly inclined surfaces will be more prone to accumulate dust and dirt

Maintenance: a simple periodic cleaning with water may be sufficient to prevent the dust from penetrating into the cementitious material because the cement surface guarantees an excellent level of durability with consequent reduction of maintenance costs (frequency and method of maintenance). It is important to underline as the frequency of such cleaning depends on the level of aggressiveness of the environment and the type of surface finish of the building.

A fundamental action, often not carried out, is to act to "adjust" the construction details that tend to generate stains and streaks on the surface due to the drain or rising water.

As far as the **CONSTRUCTION PHASE** there are two aspects to consider:

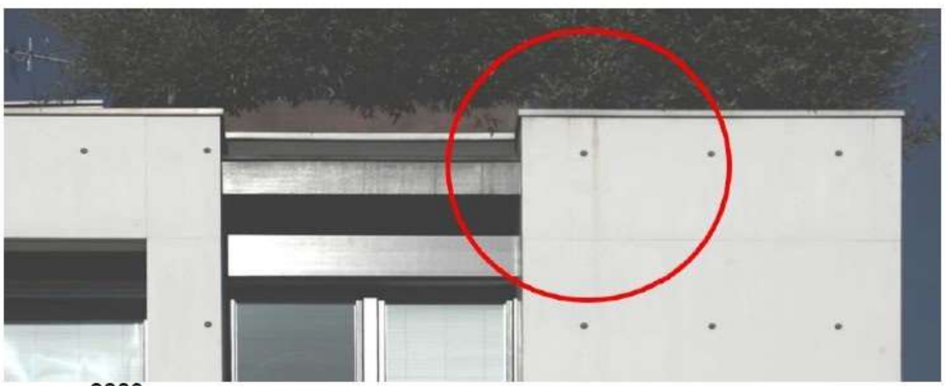
- **MATERIAL QUALITY**
Is the definition of the mix design: selecting the most suitable aggregates, cements and additives, according to optimal dosages and granulometric needs

- **INSTALLATION TECHNOLOGY**
Is the set of technological activities used in the production and installation phases of the material (concrete, precast panels, drymix mortars, cement paint, etc.).

An important choice is the formwork that can allow very different surface finishes to be achieved.
Also the surface treatment is a key point for the aesthetic maintenance of the surface.

For example, there is evidence that the application of some waterproofing agents could compromise the aesthetic appearance of the surface by increasing the adhesion of the dirt.
In the case of cladding with precast panels, the choice of the type of connection between the panels to channel the water in a convenient way is also decisive.
This aspect, which is closely related to that of the attention to detail mentioned above, is very evident in the example below (Fig. 8). Here it can be observed how the criticality in the drain of the rainwater emerged immediately and how an intervention on the construction detail could have avoided the aggravation of the stain over time.

2008 2019



2008

2019

Fig.8 – Self compacting concrete – fair-faced white photocatalytic concrete

The construction of the building lasted about 2 years and this time it was enough to highlight where the water drainage will create imperfections if no action is taken.

2011 2019

Fig.9 – Precast panels white photocatalytic concrete

In July 2019 the surface of the building is in excellent condition.

- the rough surface has not adversely affected and there are no signs of dirt or particular stains

- even the color is homogeneous on all surfaces

- maintenance has never been done on the facades of the building.

Has been observed that, if there is a criticality in the design or construction phase, there is a deterioration starting from the first months of exposure to atmospheric agents.
In this case is necessary to analyze the structural details in order to modify the details avoiding areas with moisture concentration and water drainage on the façade.

FAÇADE BUILDINGS MAINTENANCE

Here are some considerations on maintenance, coming from the analysis of buildings built with photocatalytic material, but extensible at the general level:

- there are **no compulsory periodic maintenance** activities for the aesthetic panels covering the buildings (regardless of the function of use of the buildings themselves)
- some precast producers, who have worked with TX Active concrete for prefabricated elements, suggest that customers perform **periodic maintenance** of prefabricated concrete constructions **every 3-4 years**
- in order to have an aesthetically valid surface, several cleaning and maintenance company provide the following information:

	Horizontal surfaces	Vertical surfaces
Curtain wall		Every year
Metal (Alucobond)	Every week – sills Every year – flat roof	Every year
Cement (TX based)	Every year	Every 3 years

Tab.5 – suggested surfaces maintenance

With a cleaning according to the indicated deadlines, it is possible to have clean surfaces using only of water, with obvious environmental and economic advantages.
In particular, cementitious glasses and coatings must be cleaned with a high-pressure cleaner while metal surfaces with a purified water system.
On the façades made with Alucobond, the streaks of the rain can be seen after a short time. For this reason it is important to ensure that the water that dilutes the façade is clean (weekly cleaning of the sills).

Furthermore, in the case of cleaning over 2 years it is no longer sufficient to use water but it is necessary to use specific products (alkaline) with longer cleaning times and environmental damage.

In general it can be said that the cost of maintaining a façade is determined by the time required for its cleaning (in terms of working hours) and by the rental of equipment for any work at height.
Assuming to have two surfaces of the same size: to clean a metal or concrete facade it takes 30 to 50% more time, compared to a curtain wall façade. These duration times refer to normal cleaning with a pressure washer / pressure washer.

In general, we can say that **cleaning a cement facade every 3 years represents an economic saving on maintenance costs**, in the time life of the building.

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