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To cite this article: Agnieszka Rek-Lipczynska 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 102029

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# Purification of the Air in the Historic Cities of Towns

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**Abstract.** Air pollution observed from the beginning of the industrial age has had a negative impact on the health, quality and life expectancy of the inhabitants of urban agglomerations. The problem of particulate and gaseous pollutants in PM 10 fine particulate matter and PM 2.5 suspended in air is a particular threat. The emission of harmful substances is spatially and temporally differentiated in the urban area and depends on the degree of urbanization and the level of vehicular traffic as well as the season of the year. City centres filled with compact buildings of historic character are a special issue in the planned and implemented urban regeneration strategy. The multidimensional issues of the protection of the historic structure of the city centre are more and more important in the aspects of revitalization processes in line with the sustainable development of cities. The surface of the facades of the tenement houses currently undergoing renovation works can be used as planes used with the help of the latest technological developments for air cleaning processes. The first part of the article presents technical and technological possibilities applicable to the development of facades of architectural objects. In addition to vertical garden technologies, which are increasingly successfully used in architectural realizations, the latest developments in technology and material engineering, including the importance of titanium dioxide (TiO<sub>2</sub>) - TiO<sub>2</sub> nanoparticles, as a component of building and finishing materials, such as cement and facade paints. Titanium dioxide from the 20s of the 20th century was used as an effective component of paints with excellent properties of opacity and bleaching pigments. Building materials containing TiO<sub>2</sub> nanoparticles have revolutionized the building materials market at the beginning of the 21st century thanks to their special self-cleaning, bactericidal, anti-static and air-cleaning properties. These materials have also been used in conservation work. The second part presents examples of implementation of conservation measures using the latest material technologies and examples of green wall projects and the effects of these works. To sum up, the article focuses on the issue of facades in architectural objects of inner-city buildings and adaptation possibilities of these areas for the purpose of air purification and improving the quality of life of urban residents. The revitalization activities implemented in the spirit of sustainable development are currently correlated with the challenges for contemporary measures to protect cultural heritage.

## 1. Introduction

Diagnosis of an increasing excessive concentration of particulate matter (TiO<sub>2</sub> nanoparticles) and evaluating population's exposure to its number density is an important factor shaping public health in urban areas. In most cases, exceedances of air quality standards refer to the winter period in which their highest frequency is recorded. As the results of numerous studies show, the environmental exposure to elevated concentrations of particulate matter is related to the intensification of negative health effects. Human exposure, especially to fine particles (with an aerodynamic diameter less than 2.5 µm), increases the risk



of developing cardiovascular and respiratory system diseases in connection with an increase in hospitalization and a decrease in life expectancy. Epidemiological studies have also shown that air pollution increases the risk of lung cancer. For this reason, in 2013, the International Agency for Research on Cancer (IARC) classified suspended dust as a carcinogen for humans [2]. Over 92% of the world's population inhale unhealthy air and over seven million people worldwide die because of smog.

## **2. Contemporary technical and technological possibilities applicable in the development of facades of historic architectural objects**

The striving to improve the living conditions of people in the urban environment is the main goal of the natural regeneration of cities. In the face of contemporary climate problems, which globally embrace the World, striving to shape favourable environmental conditions with reduced anthropogenic burden is an important scientific and research issue. As part of the environmental revitalization of cities, activities are undertaken that stimulate the formation of favourable bioclimatic conditions; protecting people and building objects against natural catastrophic events; increasing the perceptual-behavioural potential of the natural environment and stimulating its positive impact on people, in particular the increase in the aesthetics of the city landscape [1]. The natural regeneration of cities is a complex process that includes all threats, particularly the comprehensively captured issues of urban regeneration should be an integral part of the conditions of sustainable development. The multifaceted nature of the issues requires undertaking corrective actions both in the area of modernization of buildings, infrastructure and improvement of the natural environment. All components of the urban landscape should be repaired. The dense central tissue is most exposed to any negative factors, both culturally and naturally.

The issue of revitalization of urban areas is also an issue that is part of the cultural heritage protection program. Historical architectural and infrastructural tissue of cities, including downtown buildings and districts connected to cities in urbanization processes, are an important component of the city structure. Protection of the historic urban structure is a part of the issues of monument conservation areas. In the last decade, the traditional approach to this issue has been verified, assuming maintaining the historic buildings in an unchanged form. All environments agree that old-town teams must be modernized and must be transformed towards adapting to new functions, standards and needs. This issue is being solved by the Recommendation on the Historic Urban Landscape adopted by UNESCO, constituting a doctrinal document formulating a new approach to the protection of historical cities. "Records of comprehensive heritage treatment", from the point of view of heritage protection should be assessed as positive. Their value lies in two elements. First, they recommend and emphasize the need for a holistic perception of heritage. They indicate that all heritage elements - material and non-material - should be included in the analysis and protection. This way of treating heritage was present in the modern conservatory theory, but its consistent repetition in such an important document is imperative. Secondly, it is positive to emphasize the need to take non-conservative factors into account in historical town protection and development programs. This remark concerns elements such as modern growth, opinions of local communities, sustainable development, etc. These factors should be exceptionally prepossessed in historical town protection programs as a positive element of the HUL Recommendation. On the other hand, the extent to which these non-conservation factors should be taken into account is very important. This problem caused the separation of the problem group named "Entries regarding the heritage position in the city". These records recommend treating heritage protection only as one of the factors considered in a historical city. They recommend that communities define values for protection and specify the forms of their protection. These records also oblige conservators to share responsibility for the urban development process. And all this means that they can lead to the weakening of the importance and superiority of heritage protection among other purposes [3]. Modern visions of cities and all processes occurring in them together with revitalization processes such as the one created in 2003 The new Athenian Charter are focused on the so-called City Consistent. Many factors influence the city's cohesion. The assurance of "contact with carefully maintained elements of cultural and natural heritage" is emphasized as important. The declarations contained in the Leipzig Charter for the sustainable

development of European cities from 2007 can be considered the continuation and development of the assumptions of the New Athens Charter.

The city centre development of Polish cities, despite its historic character, is often not subject to conservator protection. The modern instrument of cultural heritage protection in Poland is the provisions of the "local zoning plan", which provides the most important aspects of protection such as: protection and restoration of all cultural heritage resources, - adequate exposure of elements of space commonly recognized as valuable, which are a distinctive feature, - harmonious creation of the contemporary cultural landscape, however with respect for the history and tradition of the place. Historic buildings are usually covered with precious plasters. The historical value of the authentic tissue of the object should be subject to absolute protection. In buildings that are not entered in the Register of Monuments but have a historical value, modernization works are practiced, just like on contemporary objects. Therefore, general building renovations, modernizations and reconstructions are carried out, and facade elevation plasters are often replaced or disappear under the thermal insulation layer. In this case, it is necessary to strive to preserve the original substance as much as possible and to preserve even small fragments of the original tissue. Leaving the so-called "Witnesses" or fragments of the original is a good practice. Preserved plasters can become a source of valuable information for future generations of both old stylistics and technology. Naturally, 100% authenticity cannot be maintained, especially in facilities of lower historical value. Hence, maintaining even fragments of the original is a valuable activity.

Modern materials that are the result of material engineering enter all areas of human life, what makes them a crucial part of conservation application or modernization works. Nanotechnology as a rapidly developing field of science is widely used in various fields, including material science. The unique properties of nanomaterials and their application potential cause great interest in these products. One of the areas that uses the achievements of this modern technology is construction. Nanomaterials or their modifications are widely used. With the help of nanotechnology, not only new building materials are introduced, but also traditional materials such as wood, steel and concrete are modified. Nano molecules used in coating technology, for example painting or aerogel nanostructures, are revolutionary achievements in material science, which thanks to their numerous properties gain recognition of the most demanding construction sectors, such as those related to the preservation of monuments. Nanocoatings can reflect or absorb UV radiation and have superior scratch resistance, anti-bacterial and self-cleaning properties, but they are also capable of purifying the air. A good example here can be sol-silicate paints that effectively took part in the market of traditional silicate paints. The possibility of application on any substrates meant that these paints also dominated the part of the market previously reserved only for dispersion paints. In addition, various modifications and variations have opened up completely new possibilities for mineral paints. Introduced, among others a sol-silicate paint with the addition of  $\text{TiO}_2$  nanoparticles that have photocatalytic properties. Hydroxyl OH-groups are formed on the surface of the paint containing nanocrystalline titanium dioxide, which oxidize and break down various types of organic soils, such as fats, oils, exhaust gases, bacteria or odorous gases. During exposure to ultraviolet (UV) rays,  $\text{NO}_x$  harmful nitrogen oxides pass into harmless  $\text{NO}_3^-$  - nitrate ions, which react with rain water and form nitric acid, which is neutralized on the surface and rinsed off by rainfall. Similar processes take place in the case of sulphur oxides [4]. An important feature of photocatalytic paints is the durability of colour, which does not change under the influence of UV radiation. Titanium dioxide  $\text{TiO}_2$  is a compound commonly used in many industries. Of particular importance for most applications is its colour, which is a white colour pattern (titanium white). For this reason,  $\text{TiO}_2$  is an important raw material for the production of pigments and paints. Special photocatalytic paints containing nanocatalysts, which are titanium dioxide nanoparticles, remove sediments that settle on surfaces. In addition, they clean rooms with unpleasant odours, harmful fumes and gases, and limit the growth of bacteria and mould. During the photocatalysis process in the presence of light and oxygen, polluting particles settling on the painted surface oxidize and transform into harmless substances. Self-cleaning coatings are also applicable in facade paints. They also use titanium dioxide and silver nanoparticles. Thanks to photocatalysts, they are easier to maintain. Another type of

nanoparticles used in facade paints are quartz nanoparticles. Superhydrophobic polymer materials, applied in the form of a thin foil to façade elements, also protect them against dirt [6].

The modern product enabling ecological use of concrete is developed by Heidelberg Cement - cement TioCem®, available in two varieties (CEM II / AS 42.5 R and CEM I 52.5 R), which in its composition contains nanometric titanium dioxide in the polymorph anatase, having photocatalytic properties. The use of TioCem® in the concrete mix allows reduction of harmful compounds present in the air surrounding a concrete building, as well as removal of impurities covering over the years the concrete surfaces of buildings and engineering structures. The nanocrystalline titanium dioxide contained in the TioCem® cement, exposed to UV rays, is activated. In the further phase of this process, in the presence of rainwater on the concrete surface, which consists of cement containing TiO<sub>2</sub> additive, hydroxyl OH groups with strong oxidizing properties are formed. Then, the natural oxidation process accelerates the decomposition of harmful compounds contained in the air surrounding the construction object, as well as compounds that pollute the concrete surface. As the authors emphasize, it is extremely important that titanium dioxide as a photocatalyst is not consumed during reactions, which makes these processes long-lasting and renewable. This is extremely important for economic and aesthetic reasons. It is worth noting that in addition to reducing airborne contaminants through active concrete surfaces made with TioCem® cement, this concrete also has self-cleaning properties. [5] Photocatalytic cement in its composition contains nanocrystalline titanium dioxide. The photocatalytic properties make TiO<sub>2</sub>, under the influence of UV radiation and in the company of rainwater on the concrete surface, accelerate the breakdown of harmful substances. Cement with the content of nanocrystalline titanium dioxide is also characterized by superhydrophilic properties, i.e. the surface made with this binder has self-cleaning properties. An important aspect is that titanium dioxide, acting as a catalyst, does not wear out during ongoing processes, thanks to which the phenomenon of air purification is constantly renewable and long-term. One of the most well-known objects made with the use of nanoparticles is the Jubilee Church in Rome. Photocatalytic concrete with the addition of TiO<sub>2</sub> was used for its implementation, which has self-cleaning properties [6].

Today the green architecture design is by definition interdisciplinary; it requires the collaboration of engineers, planners, physicists, sociologists, economists, and other specialists, in addition to architects. Green building practices aim to reduce the environmental impact on contemporary understanding of ecology has fundamentally changed the way in which buildings. Correlating digital morphogenesis and ecology, architects can develop a new framework for architectural design that is firmly rooted within a biological paradigm, and thus concerned with issues of higher-level functionality and performance capacity [8]. Introducing greenery systems on roof surfaces and building vertical gardens is beneficial for maintaining biological balance in urban systems. Green roofs and facades have a number of advantages. Their use affects the improvement of air quality, regulation of thermal conditions and improvement of the microclimate. Green façade systems also help to maintain biodiversity. The aspect of shaping the environment is also not without significance. This translates into the creation of new biologically active spaces, which contributes to shaping the landscape through its enrichment and diversification both in terms of increasing the number and diversity of plant species, but also by creating conditions for increasing the number of animal species and their numbers in urban areas.

Green roofs contribute to the reduction of air pollution levels. Air pollution in urban areas with such compounds as: nitrogen oxides, carbon, volatile organic compounds, car exhaust, create toxic combinations that pose a health hazard to residents of urban centres. Urban greenery improves the quality of air. One square meter of green roof is capable of binding 0.2 kg of volatile toxic substances per year. The advantage of green roofs is that they can arise in city centres without taking up extra space and thus cleanse the most vulnerable parts of the city.

The areas of green roofs can be new places for natural habitats. Green roofs can compensate for some of the green areas lost for the construction of new buildings in city centres. Many insects and birds can find shelter and nesting places. Green roofs are considered as additional thermal insulation, which reduces the consumption of energy for heating or cooling the building. The soil substrate used in the construction of a green roof acts as a natural insulation, contributing to the reduction of energy

consumption in buildings [9]. In 2016, NASA published a list of plants that most effectively remove harmful substances from the air, such as formaldehyde, benzene or ammonia. There are 18 plants on it, among them *Dracaena marginata*, philodendron or common ivy, while the most valuable is living moss.

Vertical gardens have been successfully created all over the world for 30 years. However, it is not a particularly popular technology, mainly due to economic reasons. The advantages of green walls include both ecological advantages, which can include: increasing or shaping biodiversity, reducing air pollution, and improving urban aesthetics, as well as economic advantages related to thermal insulation. The most important feature is the reduction of air pollution levels. Like green roofs, green walls play an important role in capturing pollutant particles and accumulating them in the green mass [10]. Improvement of urban aesthetics, such as plants on the walls help to alleviate the harsh aesthetics of urban spaces. Moreover, just like green roofs, they protect buildings against harmful effects of rain, hail, UV radiation and others [11]. All advantages of greening of architectural surfaces have influenced the introduction of new legal regulations concerning the creation of new construction projects in city centres. In countries such as Canada (since 2009) and France (since 2015), the developer's obligation to green new construction projects emerging in city centres has been successfully implemented, however the idea of ecological roofs is currently being implemented. This idea is widely implemented in the USA, Australia, Italy or Germany, and increasingly in other European countries [12,13].



**Figure 1.** Green Roofs in Rome [12]



**Figure 2.** Karlsruhe, Ulrich's Flohrer private roof-garden [13]

### **3. Examples of the implementation of conservation activities using the latest material technologies**

In Poland, the described issues find their answers in architectural projects in recent years in an intensified way. Material engineering achievements are becoming commonplace. These latest achievements are more often used by building investors in new projects as well as in the modernization works of historic buildings. Sol-silicate paints, especially semi-transparent paint, for the integration of coloured plaster, brick, stone or concrete surfaces are very popular. The properties of this paint make it possible to preserve the original structure and texture of the surface, while eliminating the heterogeneity or discoloration resulting most often from previously made local repairs. The transparent coating that can be obtained with this paint is an important value in renovation works. It extracts the value of the original coating, which is why it was used in the renovation works of leading Polish monuments such as: "Sukiennice" and Wawel Royal Castle in Krakow, Centennial Hall or church "Czterech Kopuł" in Wrocław [14,15].





**Figure 3.** „Cloth hall”, Krakow, Poland [14]



**Figure 4.** Wawel Royal Castle, Krakow, Poland [15]

Krakow is a city in which the highest concentration of toxic compounds in the air is recorded throughout the whole year. Extensive anti-smog activities were undertaken in this city. One such initiative is the smug-winning Smogathon initiative launched in 2015. The capital of Małopolska is taking decisive action to eliminate the problem of smog. There is a good chance that in 5-10 years Polish cities will look at Krakow as a model of winning the battle for clean air. Smogathon is an initiative aiming to fight the smog with innovations and technology. It supports, among others, London and Warsaw branches of Google Campus, representation of the European Commission in Poland, as well as the association Berkeley Energy and Resources Collaborative, operating at the University of California in Berkeley and the Indian University International Institute of Information Technology.



**Figure 5.** First prize in the architectural competition Revitalization of "Closer Space 2106-2022" Szczecin, Poland.

Studio: DOMINO Grupa  
Architektoniczna: Wojciech Dunaj, Rafał Stemporowski, Karolina Kopańska, Izabela Chruściel, Anna Drygalska, Anita Dunaj [16]



**Figure 6.** Architectural competition, realization "Green Roofs" 2015, Lodz, Poland

Studio: DOMINO Grupa Architektoniczna: Wojciech Dunaj, Rafał Stemporowski, Karolina Kopańska, Izabela Chruściel, Anna Drygalska, Anita Dunaj [17]

“Green Backyard of Szczecin” is a revitalization program that has been successfully implemented by Szczecin's ZBiLK since 2008. Thanks to this program, neglected courtyards at community houses regain their former splendour. During the 9 years of the program, the amount of municipal co-financing amounted to approx. PLN 9 million. This allowed the renovation of a total of 101 yards.

Thanks to the successful implementation of the program covering its backyards in Szczecin, ZBiLK launched in 2015 for the first time a twin program called Green gardens. Its aim is to renovate urban green areas located in front of the tenement houses of housing communities. Last year, thanks to communal co-financing, over 16 gardens underwent renovation.

Another initiative responding to the still poor air quality in Polish cities is the program implemented since 2016 in Szczecin under the name Revitalization of "Closer to space 2106-2022". The activity of the Szczecin Social Building Society with the support of the City of Szczecin focuses on the revitalization of downtown development. The revitalization of downtown tenements brought by Szczecin's TBS together with a comprehensive reconstruction of their surroundings helped to create better living conditions for the residents. The effects of this can be seen in the quarter 27, quarter 23, whose reconstruction took place as part of the RAZEM revitalization program or in the renovated part of the 33rd quarter, where the tenement house will be put into operation and the outbuilding in street Jan Karol Chodkiewicz 8-9 [16]. As part of the project, further works are being selected on the basis of design contests. In 2017, the architectural concept of the Domino Design Studio was awarded. The team of Domino Studio can be proud of other prizes related to the revitalization of urban areas. In 2015 the team was awarded the IV prize in the architectural and implementation competition "Green Roofs" - for the concept of reconstruction of post-factory buildings located in Łódź at street Sienkiewicza 61a and 63 together with the surroundings, taking into account the performance of green roofs [17]. The proposed design solutions refer to the industrial character of the place and are subordinated to the historical context. The new form of the green roof does not interfere with existing buildings, it is a light form, in a subtle way separating itself from the historical substance. A braided green ribbon with a characteristic path connects all buildings, giving the opportunity to create a homogeneous, cohesive space and allows the use of the potential of space in its entirety. The organic form of the green roof, naturally referring to the open landscape, adds dynamism to the static form of the existing building. The new roof form is strongly accentuated only from the side of the Schiller passage, switching to the cubature of the added glass façade that houses the café area on each floor. This solution allows linking the new space located on the roof with the public spaces of the Schiller Passage and other squares.

#### **4. Results and discussions**

The issue of façades in architectural buildings of the city centre and the adaptation possibilities of these areas for the purification of air and improvement of the quality of life of urban residents is a problem widely discussed in the world of science. The revitalization activities implemented in the spirit of sustainable development are currently correlated with the challenges for contemporary measures to protect cultural heritage. The conservative scientific community related to the protection of cultural heritage is opening up to new problems related to urban environment pollution. The new conservation doctrines allow activities that modernize the historical fabric of the city. These activities are related to the needs dictated by new standards. The issue of revitalization of inner-city areas is multifaceted. The city structure allows for the development of various modernization strategies depending on the specificity of the place.

#### **5. Conclusions**

In the case of downtown development, we have at least three fields of activity. In the foreground are the facades of tenement houses, which usually have a rich decorative program and finishing in precious plasters. Thereafter, there are buildings of outbuildings, which usually have a simplified form without architectural decor. This second plan is most often subject to far-reaching transformations in modernization processes. It is in this second plan that it is possible to apply the latest technologies in material engineering and the so-called "Vertical gardens". The third plan is new investments that complement cavities in antique tissue. These are usually modern architectural solutions.



### Acknowledgment(s)

I would like to express my special thanks to Professor Krystyna Januszkiewicz for her invaluable substantive support.

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