Towards Clean Air in Turkish Cities: Events in the Urban Space

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Abstract. The present paper is focused on a new possibility to resolve the problem of air purification in highly urbanized areas through architectural and urban design. The aim of the research is to develop an architectural form as air-purifiers especially dedicated to Turkish cities, forms which will be integrate local tradition and high technology solutions. The forms are treated as events in the city to demonstrate the process of cleaning the air with use TiO₂. The first part of the research includes studying local tradition in search of forms that will be understandable for the inhabitants and associated with Turkey. The second part of the research depicts possible usage of Titanium dioxide (TiO₂) technology - nanoparticles of TiO₂, as a building materials component. These components are the latest findings in the field of nanomaterials development, and their effectiveness due to the usage of the photo catalysis, which depends on eliminating various atmospheric pollutants and especially cleaning the atmosphere from nitrogen oxides. The result of this research is the design of energy efficient biomimetic architectural forms that can be a component of public space in every city in Turkey. In conclusion, the paper emphasizes the usage of titanium technology and local tradition, open a new way in architecture and structure designing in the urban public space. This is indispensable to improve citizens' health and to clear the atmosphere from nitrogen oxides or the volatile organic compounds and serves also as the basis to newly-built communities.

1. Introduction

Global air pollution map reveals 2,000 cities suffering from dirty air. PM₂.₅ air pollution is the largest environmental health risk in the world, responsible for millions of premature deaths every year. Although cities occupy approximately 2% of global surface, they are responsible for 70% of global energy usage [1], 75% of global resource usage and 80% of total emissions. As waste generation is approximately in parallel to resource consumption, urban areas are responsible for toxic and solid waste generation and air pollution, too. Global population is believed to reach 8 billion by 2025. It is also thought that this population will live in metropolitan areas. These increases in risk are based on the Global Burden of Disease risk model which is developed from dozens of epidemiological studies around the world covering data from millions of people [2]. Emission control techniques and programs that reduce air pollution are an important component of air quality management strategies; however, options that directly remove pollution or reduce exposures also exist that can further mitigate the impacts of air pollution in urban areas.
2. Problem air purification in big Turkish cities

Air quality in Turkey is a big concern: measurements show that citizens all over the country breathe in air that is considered harmful to health. Over the past decade, scientists have been uncovering the short- and long-term health impacts of ingesting the pollution in big cities, in order to try to tackle the growing mortality rate. There are several epidemiological studies indicating significant relationship between high air pollution levels and the number of patients who are admitted to the medical units in Turkey [3]. In 2015 the air quality standard for PM$_{2.5}$ and concentrations of PM$_{10}$ were much higher than what the EU and the World Health Organization have set to protect health. In the last few years, thanks to the efforts of local authorities, PM$_{2.5}$ pollution level remains at the middle class. Traffic, industrial processes, domestic heating, long-range transportation of pollutants are the most significant emission sources in Konya, Karaman, Kayseri or Batman and Hakkari. The cities are facing especially secondary particulate matter and nitrogen dioxide (NO$_2$) problems depending on fixed point-source (houses, industrial facilities, etc.) as well as motor vehicle-related air pollution [4] (figure 1).

The whole area of Turkey, like other countries, is monitored. Hourly concentration observations are provided for each location in a simple text format. All times are expressed in UTC time. These data are based on the regional interpolation of real-time observations by ground-level monitoring stations. As the intent is to capture regional variations in air quality, be aware that individual air quality monitors may report somewhat higher or lower values for PM$_{2.5}$ concentrations. These data are made public, causing growing social pressures and efforts to improve air quality in cities [4].

The presented design study is an application of this holistic experimental approach in recently re-opened discussion on possibility and advisability of creating a systemic solution to resolve the problem of air purification in highly-urbanized areas. It is an endeavor of addressing the problem through analyzing the collective knowledge both from environmental and engineering fields and redefining the existing solutions through implementation of advanced technologies and materials of the tomorrow.

3. Research

Last year the problem of air purification and self-cleaning were addressed by Krystyna Januszkiewicz (Leader of Digitally Designed Architecture Lab) and faculty member at the WPUT (West Pomeranian University of Technology) in Szczecin. The research program (Climate Change Adapted Architecture and Building Structure) is focused on protective envelopes designed for modern buildings in cities under rapid development. Air purification and self-cleaning surfaces concepts have attained interest
because of their distinctive features and wide range of possible applications in various fields. There are numerous materials that utilized these technologies including interior and exterior applications such as fabrics, furnishing materials, window glasses, and outdoor construction materials such as roof tiles, and solar panels. Recently, scientists are starting to answer specific questions about how cities and the urban environment will interact in the face of global problem of air purification. The main aim of the designing research program was to demonstrate new possibilities of application the new light active building materials, as well as to develop a new architectural form that could be treated as an ecological event in the urban space.

In the first part of our research project, processes, techniques and technologies of air purification and surface cleaning by using TiO₂ and ZnO were learned. A case study was also made to find out what light active building materials are used in architecture and what properties and method of action they have. The second part of the research program goes on to attempt to solve this problem through architectural design, using the latest technology and methods. The intention of this design was to minimize PM 2.5, air pollution or to eliminate any negative environmental its impact completely.

3.1. Air purification and self-cleaning architecture with using TiO₂ and ZnO

The modern ideas of cleaning air utilize a variety of techniques and sophisticated technologies that make up the controlled-environment technology, where all key factors can be controlled with a great precision. PM$_{2.5}$ air pollution is the largest environmental health risk in the world, responsible for millions of premature deaths every year. PM$_{2.5}$ means particles smaller than 2.5 micrometers, so small that they can stay airborne for days travelling hundreds or thousands of kilometers. Their small size means that once inhaled they, penetrate deep into the lungs and pass from the lungs further into the bloodstream, affecting blood and internal organs, and increasing the risk of a wide range of diseases. Most PM$_{2.5}$-related deaths are not from respiratory causes but from cardiovascular diseases such as stroke and heart disease [5]. Recent studies have focused on the development of new methods, such as photocatalysis which, in principle, leads to the complete mineralization of the targeted pollutants.

Modern TiO₂-based coatings and treatments can reduce Nitrogen Oxide (NOx) pollutions present in air under natural external light conditions and photoactive. In areas of high motor vehicle traffic, such as in large cities, the amount of nitrogen oxides emitted into the atmosphere as air pollution can be significant. TiO₂ products can be successfully incorporated into a wide range of building materials (concretes, asphalts, paints) to produce cost-effective depolluting surfaces. The photocatalytic activity of titanium results in thin coatings of the material exhibiting self cleaning and disinfecting properties under exposure to UV radiation. The photocatalytic properties of TiO₂ were discovered as long ago as 1967 by Akira Fujishima, a scientist at the University of Tokyo, and the phenomenon became known as the "Honda-Fujishima Effect" [6].

In 2013, the Eindhoven University of Technology was developed a way to apply TiO₂ to pavements making them ‘photocatalytic pavements’. This concept can reduce smog in cities by between 19 and 45 percent, depending on conditions [7]. At the same time, students from the University of California Riverside used a similar concept but applied it to roof tiles. Each roof tile is simply covered with titanium dioxide and, as they absorb sunlight throughout the day, the tiles remove the pollution from the air [8]. However, the Hong Kong-based architecture firm IO has developed a skyscraper project (Indigo Tower), takes an active stance and addresses the problem of urban pollution by helping purify the air of our cities through a combination of passive solar techniques and advanced nanotechnology. The cleansing reaction is triggered by the use of a nano coating of titanium dioxide (TiO₂) on the outer skin of the tower. During the day the reaction is naturally powered by sunlight acting on the titanium dioxide skin. At night the photocatalyst reaction is maintained by a series of ultraviolet lights that are powered by energy collected from photovoltaic panels during the day [9].
Today, to develop a nanofiber based photo-catalytic self-cleaning surface nanocomposite is the best option. TiO2 and ZnO photo-catalysts are being widely used in a number of applications to remove environmental pollutants because of their excellent photo catalytic efficiency and non-toxicity[9].

The three-dimensional surface of the Vanke Pavilion by Daniel Libeskind is covered with 4,200 ceramic Casalgrande Padana tiles with a metallic coloration that changes as light and viewpoints shift (figure 2). These tiles are sustainable and self-cleaning, and also have air purification properties. The tiles are then finished with a metallic glaze rich in oxides (TiO2 and ZnO), giving the surface an iridescent effect, and then fired at 139 degrees Celsius. The glaze contains titanium dioxide, which imbues the tiles with the potential to self-clean and purify air. The latter is done with a photocatalytic process, in which sunlight activates a chemical reaction between the titanium dioxide and the surrounding air to produce dirt and water, which are subsequently deposited on the tile surface and washed away by rain. Upon the closing of the Milan Expo, the Vanke Pavilion, whose mass is made up primarily of these tiles, will be dismantled. The tiles will be recycled and reused in future architectural applications in China, which Libeskind said will “extend the legacy of Expo” [10].

The metropolitan areas are the most important developing urban areas with serious air pollution problems. Daniel Libeskind’s first residential building named "Sapphire" in Berlin is faceted building that literally purifies the air (figure 3). Sapphire is clad in geometric stoneware tiles coated in a layer of titanium dioxide that breaks down dirt and grime when exposed to the sun’s UV rays. The remarkable facade is clad in 3,600 Casalgrande Padana tiles, 500 of which are standard-sized while the other 3,100 tiles have been custom shaped. Each tile is specifically positioned to fit the architect’s vision, and the installation of the tiles took four months to complete [11]. When used in a particular way, titanium dioxide’s ability to remove pollutants directly from the air offers a huge opportunity in the fight to cut pollution levels in cities.
Figure 4. BSTO Bursa, new mosque, Osmangazi, Turkey, 2018-2019

The Bursa region, due to the growing industry, belongs to the more polluted provinces in Turkey. The new mosque in Osmangazi was the first communal project with its self-cleaning and air purifying glazing embarked upon by the Bursa Chamber of Commerce and Industry (BTSO). The mosque's exterior is compatible with the geometric patterns, self-renewing, self-cleaning and maintenance-free titanium zinc. With its modern appearance, it has been a project that contains the passwords of Turkish traditional structures [12].

Recently, self-cleaning materials coated with photocatalytic TiO$_2$ film and ZnO have been attractive for architects and designers. One of the product case studies was the application of a PVDF-based self-cleaning coating enhanced with ZnO NPs on aluminum panels with the stated aim of reducing maintenance requirements for the coating by increasing the level of hydrophobicity. Moreover, there are many studies on the construction of ZnO nanoparticles onto cotton fibers. Although some properties such as UV protection, antibacterial properties and superhydrophobicity have been explored, solid phase self-cleaning inspection has not been carried out [13].

3.2. Research for natural ventilation systems in the Turkish tradition

In the past, various types of refrigerating devices have spread throughout Turkey especially in masonry architecture (figure 5). First, these devices were used in ancient Iranian architecture and can also be found in traditional Persian-influenced architecture throughout the West Asia, including in Pakistan, and Afghanistan [14]. The ventilation devices called wind-towers or wind-catchers and badgirs were the most important means by which the interior was cooled.

Figure 5. a-b-c. Ancient refrigeration systems, a-b) traditional Harran system, c) wind-tower system [15]

The wind-catcher operates according to the condition of the wind and sun radiation in the region. In ancient times and in traditional buildings in arid and dry regions the air trap functioned like the present modern air conditioning system. This device is like a chimney whose end is in the underground and the top is set over a specific height on the roof and were built at the entrance of the house over underground water reservoirs or ponds built inside the house. The dry and warm wind will pass over a pond with a fountain gets cool and wet through evaporation. The building material again plays another role. Due to high fluctuation of temperature differences between day and night in this climate and night time coldness, wind-catchers which are made with mud-brick, gets cool by radiation and
convection. With chimney effect, natural ventilation is provided between horizontal and vertical places and warmed air is released from openings in upper elevations by taking wind from opening space at the bottom elevation of the design in wind direction or North direction in summer. Depending on the greenhouse effect the air heated in the chimney.

Figure 7. Cappadocia housing, plan and sections of house examples carved into fairy chimneys [15]

Fairy chimneys are natural formations in Cappadocia region of Turkey. The first settlements to take advantage of the natural heat and ventilation characteristics of fairy chimneys are these carved groups with the geological structure of the region. The fact that heat loss is low makes these rooms even more useful in winter. The problem of ventilation in interior rooms is solved by a vertical ventilation chimney [15] (figure 7).

These ancient refrigeration systems were the main source of inspiration in the design of device for air cleaning in the city in order to demonstrate new possibilities of application the new light active building materials.

4. Results: the air purifier concept design
Urban ecosystems are a hybrid of humans, natural and man-made elements whose interactions are affected not only by the natural environment, but also culture. However, technology is evolving faster than culture. Advances in technology have provided a great deal of innovative ways for it to be used beyond its initial use. Presented architectural designs aim towards to highlighting the concept of "culture" and “technology” and to underline how can their relation be reinterpreting in an ecologically oriented design.

Figure 8. The initial research design – this phase of the project considers the design philosophy and develops initial high level conceptual designs
As the main project constraints become better understood through initial site and program analysis, initial design ideas and alternative design strategies are developed for potential solutions to the design problem outlined in the project brief. Designs undertake a series of studies, in traditional design media, (handmade sketches, handmade modeling), which begin to visualize spatial strategies, structural ideas and their potential effect on the social life of the proposed project (figure 8-10). Alternative building programming strategies are explored, showing how the project can adapt itself to proposed activities and use. Parametric models are important in that they provide a high-level framework for manipulation and transformations of geometrical components during the design exploration process (figure 11-12).

![Image](image.png)

Figure 9. Shape study with using clay models and digital tools (P. Saricioglu)

Figure 10. Shape transformations with using digital tools

4.1. Envelope systems concept
The designed air purifier envelope could be covered with titanium dioxide (TiO$_2$) panels. TiO$_2$ which is a photo catalyst element and it is 100% recyclable and the product of a renewable resource. It is durable and shock resistant having durable and shock resistant mechanical strength to steel. Generally, titanium dioxide is a semiconducting material which can be chemically activated by light. The chemical reaction takes place between the super-charged ion and the pollutant, effectively "oxidizing" (or burning) the pollutant. The pollutants break down into harmless carbon dioxide and water molecules, making the air more purified [16]. In addition, the envelope could contain a complex of molecules known as Photosystem-I (PS-I), the tiny structures within plant cells that carry out photosynthesis. This system was invented eight years ago by Shuguang Zhang from MIT’s Center for Biomedical Engineering and EPFL professor Michael Graetzel [17]. In Michael Graetzel’s lab, MIT
researcher Andreas Mershin was able to adapt a photovoltaic substrate that is significantly more responsive to sunlight. He was also able to create a tiny “forest” of zinc oxide (ZnO) nanowires as well as a sponge-like titanium dioxide (TiO$_2$) nanostructure coated with the light-collecting material derived from bacteria. The nanowires not only served as a supporting structure for the material, but also as wires to carry the flow of electrons generated by the molecules down to the supporting layer of material, from which it could be connected to a circuit [17].

4.2. Supporting structures concept

According to Andreas Mershin's research, the nanowires play more than a structural role in biological materials. Just as the building structure carries loads, the nanowires allow the flow of electrons in the biological material. Developing this analogy, it was assumed that the air purifier structure consists of four synergistically cooperating support systems (figure 11). This concept simplifies the complexity of a multi-component system, as each of the four systems has been structurally optimized.

The exterior supporting system allows for multiple coating options to complete the rains creen, self-cleaning panel system, which clean the air under the influence of sunlight. This approach allows the separation of functional efficiency and the shape of the external wall system from the architectural appearance of the inside of the object. From the inside, on a light supported structure with using the shotcrete pressure method - a mixture of photoactive gypsum could be distributed to create a shell like-cave surface with UV lights. The gravitational circulation of the air is provided by openings and perforations (figure 12).

Figure 11. Four synergistically cooperating support systems

Figure 12. Final design – the Air Purifier with a kinetic perforated skin
5. Conclusions
The presented air purifier can be located in urban areas where a car traffic is heavy. His form and function comes from the local tradition of the Cappadocia region. These inspirations were used to create similarly looking engineering systems. Metaphors often help designers to understand unknown design problems, juxtaposing them with known situations. The use of smog-eating and self-cleaning coating technologies is an innovative strategy in the operation of traditional wind-catchers and fairy chimneys. Biological surface engineering using synthetic biological materials has a great potential for advances in our understanding of complex biological phenomena. Currently, biophotovoltaic PS-I based on nanostructured TiO$_2$ and ZnO offers new materials that react under normal sunlight and its design and fabrication are amenable to low-cost, iterative optimization. In a few years, you will be able to produce your own photovoltaic cells at home in remote villages using plant waste. Practicing architects have a challenging responsibility to design buildings that are environmentally sustainable with the change in the global concern regarding the use of energy and resources. This responsibility has prompted a sensible shift in trend from a biased preference of eye-catching, institutionalized building forms to more organic, humble, yet energy-efficient vernacular forms. Additionally, the local forms of construction capitalize on the users' knowledge of how buildings can be effectively designed to promote cultural conservation and traditional wisdom.

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