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Potential of air quality improvements in Sarajevo using innovative architecture approach

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ABSTRACT

Air pollution and population health related to it is one of the main issues in Sarajevo in the past few years, especially in the winter time. Reason for that is combustion of coal, oil fuel and other harmful emissions that leads to creation of air pollutants such are: particulate matter (PM), sulfur dioxide (SO_2), nitrogen dioxide (NO_x), and creation of Ozone (O_3). This study addressed the question regarding possible solutions for improvement of air quality by removing NOx emitted from the cars in the particular area of urban core of Marijin Dvor in Sarajevo using innovative architecture approach. Basic principle introduced by this paper considered outdoor application of TiO_2 coating, in accordance with previously conducted studies. First part of research was conducted bysnowball research method which was used for accumulation of similar research material, while later study was completed using mixed method research design with explanatory research method which provided analyses, comparison and calculation of expected outcomes of applied innovative solutions as a mean to reduce pollution. These innovative approaches were implemented as coatings of TiO_2 on elevations and paved areas next to the main road. Total area covered by TiO_2 was 15 778 m^2. Results strongly indicate that usage of TiO_2 coating as innovative approach reduced the amount of NO_x emitted by cars per year by 52,39%. This amount of NO_x removed after treatment indicates that method proposed in this study was very effective and suggests that this study can contribute to further analyses and lead to possible implementation in the future.

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1. Introduction

Together with a growth of urban and metropolitan areas, growth of population density and transportation related activities occur [1]. According to the findings by the United Nations, in 2007 half of the world's population was living in urban areas[1]. Recent years are capturing continuous increase in the proportion of the population living in urban areas [2]. While cities during history were considered as a society's core of

[1] United Nations. World Urbanization Prospects: The 2003 Revision. New York: United Nations, 2004

innovation, richness, and development, more pessimistic aspect regarding crime, disease, and pollution was also established [3].
As a result of raising transportation, major deficiencies associated with the health and pollution are becoming unresolved. Furthermore, researchers are trying to address these problems examining and testing innovative methods and techniques. According to Durakovic, increase in energy consumption is linked with increase in consumption of non-renewable energy source [4], thus suggests development of a design based on the energy storage that will reduce building energy demand and incorporate passive design strategies [4]. Reducing energy demand is achievable through better insulation of building envelope using new materials [5][6]. Aside from innovative solutions for future design, several studies done in the recent years were analyzing performances and implementation of titanium dioxide (TiO_2) coating practices in the process of removing harmful air pollutants, by transforming them into harmless and environmentally-friendly air compounds. Air pollution in Sarajevo has been the problem over the decades, the only time without air pollution problem was the period during the war when industry stopped, heating was minimal and automobiles were scarce. During the last few years quality of air in Sarajevo is very bad and meteorologists are often "blaming" the nature for air pollution in Sarajevo: basin position and temperature inversion creates the effect of lid over the city without the air drift under it, especially during the winter months.

2. Literature review

This research addressed the question of removing NOx emitted by cars as a mean of reducing air pollution by innovative approach defined as application of TiO_2 coatings on different surfaces. In the past decade titanium dioxide (TiO_2) emerged as an excellent photocatalyst material for environmental purification [7]. Research question covered in this study was “What are possible approaches of applying TiO2 coatings in order to increase air quality and what are outcomes regarding effectiveness of this method?”
First step taken in order to answer addressed question was aggregation of already conducted studies regarding effectiveness of TiO2 coating in decreasing the amount of NO_x in the air and reviews existing applications in practice. These studies were conducted by leading company[2] in producing TiO2 products applicable in different settings, indoor and outdoor, and on different surfaces – roofs, external walls, paved areas and roads. Researchers in the United Kingdom are even creating NO_X-removing “catalytic clothing” in which TiO_2 nanoparticles and calcium carbonate are added to fabrics, sprayed onto clothes, or applied during washing [8]. Based on the studies by Cristal, 100 m^2 of surface painted with KNOxOUT may remove the NO_x equivalent to that produced by a car driven more than 130 km, which proves good effectiveness[3]. In one trial in Manila’s Guadalupe train station, Cristal Global painted 4,100 m^2 of exterior wall and found the paint removed about 26 g of NO_X per 100 m^2 of painted surface. The company claims each painted square meter could remove 80 g of NO_X per year. Other trials that run over 4 years, a wall in London of 135 m2 was treated with another Cristal product, and reported that reductions of 60% for the NOx. The photocatalytic paint is as well reported to work in the low-light environment of multistory parking lots, capturing 2.2 g of NO_X per square meter per year [8].
According to a study on evaluation of titanium dioxide in removing air pollutants [9], the removal rate for volatile organic species is about 60 cubic meters of air per day. It further states that “these numbers are rough estimates, but are based on careful quantitative investigations”[4]. The same study labels technology of TiO2 as technically feasible, but underlines the problem of cost-effectiveness, due to the fact that reducing cost will be challenging due to the large volumes of air that must be processed.

3. Methodology

This research paper was addressed as a case study with mixed-method research design and explanatory research method, where quantitative data were followed up by qualitative.
First part of research paper was obtaining and analyzing data regarding average car emissions of NOx, traffic counting for particular urban part of Sarajevo, and analyzing innovative methods regarding air quality improvements. Data was collected by snowball method and further content analysis from the records were done. Data regarding traffic counting in the proposed area of Marijin Dvor in Sarajevo used in this paper was obtained from Ministry of Transport - Directorate for Roads of Sarajevo Canton, Traffic Counting on existing

[2]Global, U. (2017, January 20). *Cristal ACTiv™*. Retrieved from Cristal ACTiv™
[3]Global, U. (2017, January 20). *Cristal ACTiv™*. Retrieved from Cristal ACTiv™
[4] [9]

Primary city and regional network of roads jurisdiction, Road Directorate Sarajevo Canton 2015, published in July 2016, while data about car NOx emissions were taken from a study by IICT (The International Council on Clean Transportation) on emissions from EU Diesel Euro 3 passenger cars, since this engine type it is mostly used in Bosnia and Herzegovina[5]. Outdoor air quality improvement was done by removing NOx from the air emitted by cars with usage of innovative approach. This approach includes application of TiO2 coats on the surfaces next to the very crowded main road in the urban core of Marijin Dvor, Sarajevo. After analyses of different studies by leading experts and companies that produce TiO_2 coatings, further research included analyses of gained results and investigation of possibilities of air purifying using TiO2 coatings in the case study of urban core of Marijin Dvor, Sarajevo.

Study proposed introducing coats of TiO_2 on five elevations and five small squares and pedestrian paved areas in mentioned urban core. Due to different classification of these elevations regarding architectural style and importance for cultural heritage, different approaches were proposed; application of TiO_2 as an elevation painting, and addition of designed architectural elevation part "Module X" that will serve as a new design in old settings method to satisfy esthetic, and as a NO_x removal with TiO_2 coating to serve air-purifying function, in the city that has constantly growing problem with air quality, mostly due to expansion of its area, population and transportation system.

4. Case-study setup

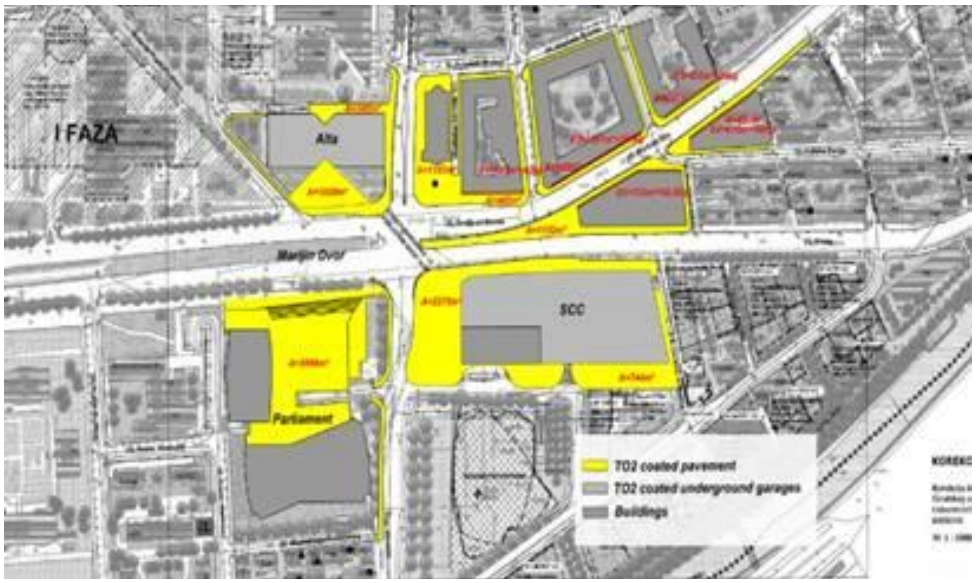

Figure 1. Map of Marijin Dvor with TiO_2 application

Air purifying was done by removing NO_x emitted by the cars from the air. It was realized by applying coatings of titanium dioxide on the pedestrian pavements next to the main road, on five paved public squares that are framing the main road, and on five elevations of the surrounding buildings in the part of Marijin Dvor, urban core of Sarajevo (Figure 1). Since this urban area partially consists of the buildings that are important part of the cultural heritage, application was proposed on two different ways: painting existing elevations and introducing new modular design element, called "Module X" that would be attached to elevations of buildings that are not part of heritage. Since "Module X" element is modular, it can be applicable on buildings with different style, dimensions and function. Total area of 15 778 m^2 was treated with TiO2. Calculating efficiency of TiO_2 coatings was done in accordance to already conducted studies about cleaning possibilities of different TiO_2 products[6].

Based on the studies by Cristal, 100 m^2 of surface painted with KNOxOUT may remove the NO_x equivalent to that produced by a car driven more than 130 km [10]. Institute for Economic Engineering Zenica published that 77% of the cars in Bosnia and Herzegovina are older than 10 years, which corresponds to Euro 3 engine.

[5]Institute for Economic Engineering, Zenica

[6][9]and Global, U. (2017, January 20). *Cristal ACTiv*™. Retrieved from Cristal ACTiv™

According to a study by Association for Emissions Control by Catalyst, Belgium, average emission of NOx for Euro 3 vehicles is 0.5 g/km [11]. Traffic counter [12] states that in observed urban area of approximately 0,5 km in Marijin Dvor pass 26,600 cars daily, which represents 6,6 kg of NO_x. The amount of NO_x emitter per year in the same area is 2409 kg.

4.1. Elevations

This innovative way of purifying the air is application of TiO_2 to the building facades. The basic principle is to coat the tiles or modules by titanium dioxide that fights the pollution near the dense traffic. Representative example for this is the hospital Manuel Gea Gonzales in Mexico. Double skin facade provides the functional, aesthetical, and healthy conditions improvement. Its modules are coated with TiO_2 and they fight the air pollution while providing the shade at the same time.

For the purpose of this study we have designed a module (Module "X") that could be applied on different exterior surfaces. The size of one module is developed from 1x1 meter grid, and due to extrusion additional surfaces would be covered by TiO_2. Total amount of extruded module covered by TiO_2 coating will be 1.82 m^2 (Figure 2).

''Module X'' (Figure 2) is a decorative architectural module that can effectively reduce air pollution when installed near traffic ways on building facades. Modules would be made from lightweight thermoformed plastic panels coated with TiO_2.

We are proposing the application of it to the southern façade of Marijin Dvor building facing the media wall of SCC shopping mall (Figure 1). Besides the improvement of the current bad condition of the building's façade, additional purifying skin will successfully contrast to the light polluting media wall of the shopping mall.

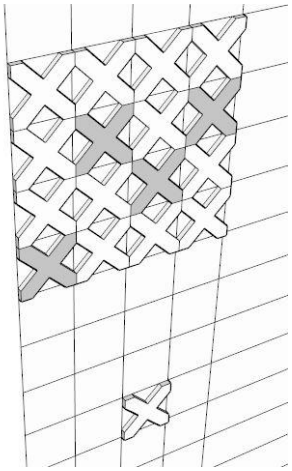

Figure 3. Facade composition using Module 'X'

One module has 1.8 m^2 coated area. The whole façade consist of 704 modules comprising the 1267, 2 m^2 of titanium dioxide coated area. According to the findings by Cristal[7], the leader company in manufacturing titanium dioxide products, TiO_2 coating of 1 m² purifies 80 g per year. Applied to the facade modules, the whole facade would remove 101, 37 kg of NO_x per year out of 2409 kg of NO_x emitted per year, or 4,2%. Further application is done by applying TiO_2 only as a painting, on the several proposed elevations in the same street. Complete surface of hereby proposed elevations is 3375 m^2, which gives the result of 270 kg of NO_x removed from the air out of 2409 kg of NO_x emitted per year, or 11,28%. Total amount of removed NO_x from coatings of TiO_2 on elevations is 371,37 kg per year, or 15,41% of total emitted NO_x per year.

4.2. Pavements:

Further setup implementation was applied on concrete paved pedestrian areas located next to the traffic zone, and were extended to five public squares, with areas ranged from 1000 to 3569 m^2. Two of them are part of exterior design of shopping malls designs and urban integration, another one is located in front of the Church and on the crossroads, while the biggest one is located in front of the Parliament building. Besides squares,

[7]Global, U. (2017, January 20). *Cristal ACTiv™*. Retrieved from Cristal ACTiv™.

TiO_2 coatings were applied on pedestrian ways in this part of the urban core. Total area with concrete pavement is 11 136 m^2. If we continue the same principle that 1 m^2 of TiO_2 removes 80 g of NO_x per year, coating this area will decrease NO_x for 890,88 kg per year, out of 2409 kg of emitted NO_x per year, or 36,98%.

5. Discussion

Total amount of emitted NO_x per year in observed urban area of Marijin Dvor is 2409 kg. Total amount of NO_x removed by specific application on elevations and paved areas after TiO_2 treatment area is showed in charts below:

1. Facades: 371,37kg per year or 15,41%

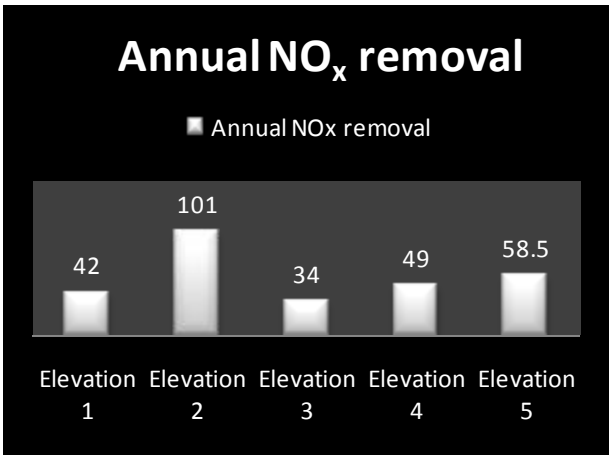

Chart 1. Annual NO_x removal per elevation (In kilograms)

2. Pavements: 890, 88 kg per year or 36,98%

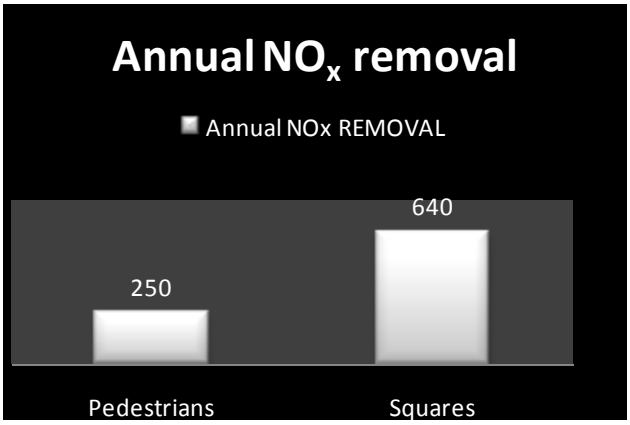

Chart 2. Annual NO_x removal from squares and pedestrian surfaces (In kilograms)

Proposed solution for reducing air pollution by applying innovative approach of TiO_2 coatings would remove annual NO_x emitted from the cars by 1262, 24 kg per year, or 52,39%.

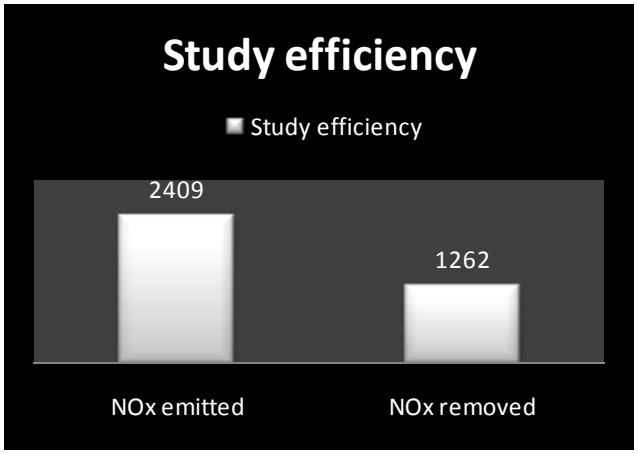

Chart 3. Annual NO_x emission and removal (In kilograms)

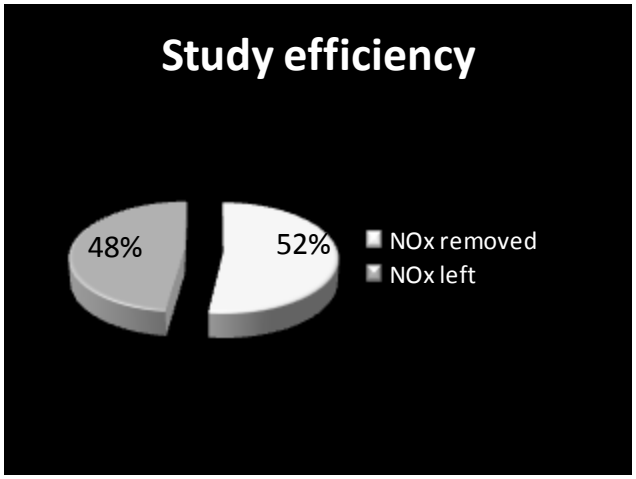

Chart 4. Annual NO_x removal by proposed setup (In percent)

Regarding the fact that this study proposed treatment of only five elevations facing main road with total area covered by TiO_2 of 4642 m^2 and paved areas of 11 136 m^2, results show that it removed more than half NO_x emitted annually by cars that pass in this area. According to the percentage gained from the calculations we can state that application of TiO_2 proved as effective.

Since the most TiO_2 coverage area was applied on pavements, accordingly it gave the best results in NO_x removal. Negative side of application of TiO_2 on pavements is implying that this method raises questions on resistance of these coatings to the weathering and loads, but it is expected that problem can be solved since there are on-going researches regarding improvement of this issue.

5.1. Cost

Total area that would be coated by this research is 15 778 m^2. Brian Pickett, business director for performance chemicals business at Cristal Global, says the paint may cost twice the normal price [10]. Average price for 1 kg of ordinary façade acrylic paint is 2 EUR[8]. According to this, the cost of 1 kg would be 4 EUR. 1 kg of paint can cover 5 m^2 in two coats[6]. This implies around 3000 kg of paint for the setup of this study, and led us to the cost of 12.000 EUR for TiO_2 coating to be applied by this study (excluding labor cost). But the labor cost is one to be predicted and calculated. If the price of painter work per 1 m^2 is 1 EUR in Sarajevo that implies 15 778 EUR for the whole job to be done.

Total cost for applying TiO_2 coating for this study would be 27.778 EUR that is 54.328 KM.

According to the amount of removed NO_x proven by this study we may say that the cost of applying TiO_2 coating is acceptable.

Maintenance

[8]http://www.jub.ba/sites/www.jub.si/files/documents-ba/jub_cenik_2014_bos-www.pdf

Since TiO_2 does not get consumed in the process of photocatalysis, theoretically it can be used indefinitely. This technology is simple to implement, and the only maintenance required is regular water cleaning during the dry season to resume good performance. However, applying coatings of it on the pavement, and elevation walls suggests that layers of TiO_2 can get damaged and it can affect their effectiveness. The main threads to the effectiveness of coating are those concerning pavements because people are walking directly over the coated area. This can affect lower durability because of traces of soles, dirt and gluing the chewing gums for example. Nowadays, studies are being conducted in the best possible method to apply TiO_2 coatings in which they will resist all possible causes of damaging it, including weathering, loads, or any other physical way of harm. There is a hope that this physical harm on TiO_2 coatings along the pavements will be solved.
Studies show that durability of in concrete coatings range between 6-11 months, and between 10-16 months in asphalt coatings [13].
This implies annual recoating of TiO_2.

6. Conclusion

While cities are in a constant process of expanding, parallel increase in the amount of pollution and degrading of natural environment are occurring. Furthermore, increased amount of pollution leaves negative consequences on human's health. Nowadays, companies all over the world are trying to develop innovative sustainable approaches with a goal to remove dangerous compounds from the air, and decrease pollution. Study conducted in this research paper examines a possibility of application and implementation of air improving techniques regarding removal of NO_x from the cars, using titanium dioxide coatings in the case study of Marijin Dvor in Sarajevo. Application was suggested in the parts of the urban core of the city, which contains different possibilities in the methods of coating. Study was conducted in outdoor settings, and suggest significant removal of NO_x. Total amount of emitted NO_x in this area is 2409 kg per year, and innovative approach of TiO_2 coatings in this study removed NO_x by 52, 39%. According to the percentage of removed NO_x together with acceptable cost of the TiO_2 paint, we can state that approach suggested in this study is very effective. Since these studies are innovative and novelty in the world, this conducted research can improve complete understanding on this topic. Furthermore, this study can serve as a basis for further analysis regarding case study of Sarajevo.

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