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Eating air pollution using building's façade technology

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ABSTRACT

The research is concerned with pollution in general and air pollution in particular. Through description and analysis, the research tackles the most prominent methods and means used in order to reduce air pollution using modern technologies. It also tackles the extent of the impact of the built environment on the natural environment. Thereby, the research seeks to reduce this effect through the architectural designer's utilization of technology systems. Thus, the general research problem is formed; showing a lack of knowledge on how to deal with the pollution problems resulting from vehicle exhaust. Further, the research tackles the studies related to the special research problem, which is the lack of knowledge of modern techniques such as (biological filters) used in the buildings, its importance in dealing with air pollution resulting from vehicle exhaust, and its impact on the local environment. The aim of the research is to study and describe architectural buildings that use such technologies and demonstrate their importance in improving local environment. This is made by forming a methodology that includes two parts; the first is represented by air pollution, its sources and cause and the second is represented by studying the technologies, indicating their types and differences and how the architectural designer used it in buildings to reduce air pollution caused by vehicle exhaust. The research reached many conclusions and recommendations.

Keywords: Pollution, Buildings, Façade

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1. Introduction

Architecture plays a major role in the relationship between the built environment and the nature of the planet earth. Our buildings are constructed to sustain our daily lives, but in order to construct them we must damage the surrounding natural environment and transform the forests, plains and grasslands into a concrete environment. Construction is a major contributor to environmental degradation and climate change. International societies like LEED (Leadership in Energy and Environmental Design, National Green Building Standard (NGBS), Building Research Establishment's Environmental Assessment Method (BREEAM) and other organizations are conducting research to develop the sustainability of architecture and seek to reduce the level of environmental damage resulting from the architectural design. Certificates issuance programs aim at defining and confirming that architectural projects run into specific environmental criteria that include energy usage, reprocessed content, air quality mechanism, and water consuming that straightforwardly affect environmental quality [1]. The purpose of this, in accordance with the new global trends, is to attempt at reaching a zero-energy building so that the building reduces the impact on the surrounding environment and aims towards providing remedial methods for environmental pollution in order to achieve sustainability. This will turn the building into a living and self-recovering organism. While programs seek to promote more biologically neutral constructions, they eventually fail to reinforce the type of measures required for combat matters like climate change, high population, behavioral and environmental reform. In the case of making a permanent change in these areas and achieving a comprehensive solution to these environmental issues, our perception of architectural design necessities a change. The constructions can no longer keep on containers for our activities; they should dynamically participate in shaping our physical and psychosomatic relationships between the erected world and the natural world. This can be made by achieving an architectural design that can involve its occupiers in upholding a healthy life and interaction with the natural environment, by using and harnessing new technologies to reflect the harmful effects on the environment. Based on the foregoing, it became clear that buildings have a great impact in the field of preserving the environment through well-known classifications, as the environments were classified into a constructed environment and natural environment. Therefore, the research will focus on the use of modern technologies represented by (biological filters) in order to achieve an integration between the natural environment and constructed environment and reduce damage resulting from the latter. For this purpose, the research will address the subject of the environment and its definition, as well as the factors that lead to environmental pollution while focusing on air pollution and how to reduce it for the purpose of reaching a healthy environment and the sustainability of different natural resources.

2. Identifying the general scope of research

The research defines modern technologies used in areas that combat the influences of climate changing, in particular metropolitan air contamination. This paper will try to validate these emerging technologies and compare each individual system. The design of the most effective technology for architectural integration and its integration into a specific project will be determined as an example of a comprehensive sustainable architecture.

2.1. Recognizing the influences of air pollution and the deficiency of existing environmental solutions

Based on a report published by World Health Organization in 2014, 7 million persons died in 2012 because of air pollution exposure, of which 4.3 million died as a result of household air pollution and the residual 3.7 million were caused by ambient air pollution. Based on the Canadian Medical Association, air pollution in Canada is estimated to account for 21,000 premature deaths, 92,000 visits to the emergency room and 620,000 visits to hospitals and clinics in a year. This results in a financial cost for illnesses caused by air pollution [3].

Looking at these surprising statistics raises the question of why there is such pollution, what are its causes, and how can we fix it? A lot of studies have been achieved to find answers for these enquiries, particularly from the standpoint of sustainable building and technology.

Architects play a key role in finding a lasting solution to the growing issues of pollution and environmental degradation. With the urban population expected to grow significantly, it will be up to urban planning and architectural design for accommodating this growing population. Buildings must be more effectual, more productive, and should provide a psychological solution to correct our behavior towards pollution in the case of supporting this growth in a responsible manner [4]. Based on the foregoing, the research shows the importance of addressing the issue of air pollution and what are the ways and capabilities available in the architectural design to address this problem through sustainable modern technologies that can be used by the architectural designer. The studies that tackled the topic of the research will also be addressed to reach a solution for the research problem.

2.1.1. Environment definition

The use of the term environment became prominent in recent years. Yet, its precise concept is still ambiguous to many, especially since there is no single definite definition that shows what environment is and identifies its multiple fields. But it can be said that environment is the whole or part of the planet earth when it acts as a vital medium that includes all organisms, water, air, and inanimate objects. This medium, alongside its inhabitants, works according to a divine system and universal laws and beliefs that last a life time [5].

2.1.2. Definition of pollution

Pollution as a term in language is taken from (polluted his clothes with clay or stains it, and polluted water), whereas pollution in the scientific concept is (a change in the ecological system of the environment), as it paralyzes the effectiveness of this system. Leading it to lose its ability to perform its natural role in getting rid of pollutants [6].

2.1.3. Types of air pollution

Air pollution can be summed up in three main types:

1- Biological pollution: It is pollution resulting from the spread of biological waste material in the air.

2- Chemical pollution: pollution caused by the spread of chemical compounds and elements in the air.

3- Thermal pollution: is pollution caused by the high temperature of fluids and materials in the air to unusual levels; the heat resulting from energy sources. In addition to dust and soil from the Earth's crust. The previous forms of pollution contribute to the material pollution of the air and the immaterial pollution which is represented by the spread of disturbing noise resulting from the wheels of work and means of transport [2].

2.1.4. Classification of air pollutants

Air pollutants are classified according to their sources: major (primary) and secondary pollutants:
1- Primary pollutants: They enter the air directly as a result of humanoid or nature activity and are called the foremost pollutants. Their natural causes are based on dust, sea salts, gases, volcanic ash, smoke from forest fires and pollen. The human causes are carbon monoxide, dust, smoke and chemicals from paint and other materials, and in cities; vehicle exhaust is a common source of major pollutants.
2- Secondary pollutants: These have formed as the main pollutants interact with other foremost pollutants or natural materials like water vapor. Instances of secondary pollutants can be represented by ozone and smoke fog.

2.1.5. Standards of air pollutants

The World Health Organization and the Environmental Protection Agency categorize these pollutants as air pollutant "standards" for the reason that they are controlled in accordance with human health or environmental health standards to determine tolerable levels. Air pollutants are the main pollutants originated in smog, and they are composed of sulfur oxides (SOx), nitrogen oxides (NOx), particles (PM), volatile organic compounds (VOC), carbon monoxide (CO), ammonia (NH3) and ozone at the level of Earth (O3 - ozone stands for a secondary pollutant, generated as volatile organic compounds and nitrogen oxides combining in the lower atmosphere) [4].

2.1.6. The role of transportation in air pollution

Although there are many sources of pollution in the environment, the research will focus on transportation, as vehicles in the world are responsible for 60% of air pollutants. Vehicles of all kinds use gasoline and diesel to produce kinetic energy, which are considered to be an important source of air pollution. This is accompanied by the number of vehicles that are constantly increasing in all countries of the world. Vehicles emit exhaust gases resulting from burning diesel and gasoline in the air at the same height that a person breathes. In general, it can be said that vehicles that use diesel are less than vehicles that use gasoline globally. Burning gasoline results in carbon dioxide, carbon dioxide, hydrocarbons, sulfur oxides, soot and unpleasant odors. Pollutants from fuel are also producing fine particles that are dangerous to human health, such as rubber and asbestos from vehicle brakes and asphalt, as dust flows on the streets during traffic [7]. Pollution rate (G / L) is depicted by Table 1 based reported by Dr. Sameh Gharaibeh and Dr. Farhan in their publication in Introduction to Ecology, p. 259 - p. 261.

Table 1. Pollution rate (G / L)

Quality of pollutants	**Gasoline vehicles G / L**	**Diesel vehicles GM / L**
1. Carbon monoxide	249.00	29.50
2. Hydrocarbons	9.62	1.80
3. Nitrogen Oxides	9.85	7.20
4. Sulfur dioxide	0.37	4.15
5. Lead	0.37	-
6. Soot	-	1.90

3. Previous studies

Many studies and theses touched on the topic of pollution and air pollution in general terms. One of which is the study of Al-Gasani which studied air pollution in the Iraqi environment, its causes, the factors that cause an imbalance in the natural balance of air, and the most significant pollutants that were classified as natural and other abnormal pollutants. The researcher classified the pollution sources in Iraq into three sources; mobile sources (vehicles) and fixed sources (combustible sources, and non-combustible sources) [8]. The study of Al-Athatra, deals with the topic of air pollution, touched on its types and sources, as well as the risk to the general environment in the city of Baghdad. These pollutants cause an effect on the temperatures in addition to harm on the local environment in the city of Baghdad. Al-Araji study further deals with air pollution in the city of Baghdad. The results of this pollution are summarized in smog and acid rain and measuring the quantities of these products and its effects on the local environment of Baghdad in different months of the year [10].
Through review of previous proposals and studies related to the general research problem, it was found that there is an architectural deficiency in the ways to deal with the problems of air pollution caused by vehicle exhaust.

As for the studies related to the special research problem, among which is Al-Alali study which touched on air pollution inside buildings (indoor places) and the factors leading to air pollution in the interior spaces and the possibility of reducing them and treating them in different ways [11]. Another study is the one carried out by Shaima. It deals with pollution from the visual aspect of the residential buildings' facades. She touched on the issue of pollution, but from its visual aspect and how it affected architecture in Basra city [12]. Ataa's study pointed to the importance of technology based on porosity in modern architecture and touched on many treatments and highlighted the characteristics and features of these buildings [13]. Dr. Ahmed's study pointed to the concept of adaptation in the buildings' out-structures and how to adapt and the techniques used for the purpose of suitability with the surrounding environment. The study touched on many examples, leading to the conclusion of the most prominent features and characteristics of these buildings [14]. Although the study is close to the subject of the research, it did not touch on the treatment of smoke resulting from vehicle exhaust by covering the facades. Thus, it became clear to the researcher through examining these studies that there is a knowledge gap represented by the lack of studies that deal with the impact of technology in reducing air pollution. Thereby, the special research problem is represented by the knowledge deficiency of modern techniques such as (biological filters) used in the buildings and their importance in addressing air pollution resulting from vehicle exhaust the research has set out methodology to achieve its goals.

In this research, the concept of pollution in general, its types and it different forms will be tackled, as well as the different technology adopted in building treatment and its importance in improving the external local environment. This is made in order to achieve the goal of the research, which is building an integrated theoretical framework on the concept of local environment's improved elements and their importance in improving the local environment in Iraq. In this regard, the study reached several deductions and recommendations.

The research aims to demonstrate the importance of the technology used in covering buildings and the extent of their usefulness to the local environment. This is made by examining the buildings in which they were used and how it can be applied to the local environment. Thereby reaching a sustainable architectural project, which focuses on dropping air pollution and promoting a constructive relationship between the inhabitant and the natural ecosystem.

The research examines the potential for the availability of technologies that address air pollution directly. Its purpose is to obtain an accurate description of the function, operation, and design of individual systems with the intention of determining which system is most feasible in terms of architectural capabilities. This is made by integrating it into project interfaces to clarify the concept of comprehensive sustainable architecture. Thereby addressing the questions; how can this be translated into a more comprehensive architectural design. What is the emerging, most effective and sustainable technology as an air pollution solution? And can it be adapted to the architectural design. In addition, in terms of integrating it with technology, the technologies can be used in interfaces to provide the best performance for dealing with air pollution in the building. For the purpose of obtaining an answer to these questions, the main research items will be addressed, in order to achieve the aim of the research.

4. Treatment of air pollution

Due to the constant increase of airborne pollutants concentration in spite of international efforts to reduce the emissions, it is obvious that fundamental industrial changes should be created to evade the dangerous and irretrievable results. Establishments in all over the world are evolving innovative ecological machineries that can filter the poisonous compounds in the atmosphere. The majority of these solutions are until now in the pilot phase, but a few reach a point of evolution to be cost-effectively feasible in the next two years. These designs not only introduce new engineering techniques, but also introduce interesting new architectural techniques that combat air pollution. Three systems will be discussed that deal with air pollution.

4.1. Deep technology in achieving total sustainability

Three scientific systems which are materials science, architecture, and mechanical engineering have been integrated to reach a technology that addresses outdoor air pollution through building facades. These new technologies that are being developed play an imperative role in addressing air pollution and climate change. This research identifies three types of the leading technologies that seem to be sufficient and efficient in treating air pollution (Titanium dioxide coatings, biofiltration, and direct carbon capture). Every system is distinctive in its air filtering method. It is possible to merge these three systems into one project or adopt one system to treat air pollution. This is determined by the degree to which the following points are achieved:

A) The selected system is versatile, meaning that it can be physically manipulated to allow catalytic architectural redesign.
B) The system is cost-effectively practical, which means that the expenses of constructing and operations will not prevent developers from investing in technology.
C) The selected system proves to be better than other treatment techniques in terms of its ability to filter pollutants from the atmosphere.
D) The used system will reflect the most fitting visual and experimental characteristics for developing remedial solutions for buildings to provide a healthy environment and contribute to reducing environmental pollution.

4.1.1. First system: Direct air carbon capture system

This system captures and isolates large quantities of carbon dioxide and carbon monoxide, in addition to other contaminants in the atmosphere.
Carbon Engineering Company had been founded in 2009 by David Keith, headquartered in Calgary, Alberta, and is supported by over $ 3.5 million of private investment from famous people like Bill Gates and Murray Edwards. They are presently emerging the DACC system and have been investigating their project since 2014 [5].

The air surrounding the building is drawn through an air conductor connected to the building's facade. It is drawn through a large draft fan that pushes the air drawn horizontally through a room filled with packing materials organized in the form of structures covered with a very strong hydroxide solution. This solution is pumped to the top of the system and flows to the inside of the packing structures, and the carbon dioxide and carbon monoxide are captured from the air drawn through the system channels. This solution, which contains the captured carbon dioxide, is sent afterwards to a regeneration cycle that extracts carbon dioxide while at the same time recreating the original chemical solution to be reused in the air conductor. The extracted carbon dioxide is then compressed into compressed granules and can be reused as fuel. These two processes are working continuously and in a sequential manner in which the inputs to the building's cover are carbon dioxide and carbon monoxide captured from the air surrounding the building. As for the outputs, after passing through the whole system, they are pure carbon dioxide, which is transmitted in certain channels to the ground or converted into pressurized granules that are sold or used in industrial applications. Thus, the air pollution surrounding the building is treated with a commercial benefit to the owners of the building [15].

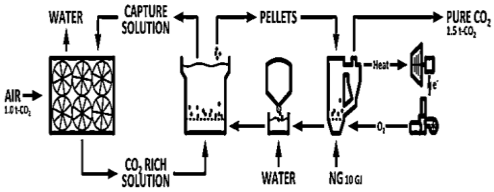

Figure 1. Carbon engineering's air captures process

4.1.1.1. Design flexibility of the direct carbon capture system

The design of the air capture system is not sufficiently flexible with regard to the architectural design as it is for the performance of its function. Therefore, at this stage of project development there is not much room for architectural re-imagination (in the case of developing real projects and adding this system to the construction) there are some creative capabilities for air intake and exhaust valves. Nevertheless, the system cannot really be changed afterwards. As this system is still in the prototype stage, which means that it depends on continuous experiences and design tests to generate the best performance possible. Perhaps once the required competency levels are reached, the system can be more open to architectural design. Up till now, the design is incomplete in terms of aesthetic and technical function [5].

4.1.1.2. The cost of adopting direct carbon capture system

The American Physical Society (APS) and Prof. Kurt Zainz House at the Massachusetts Institute of Technology (MIT) have tested the capabilities and actual cost of a direct carbon capture system and estimated the total cost of carbon isolation at about $ 600-1000 per ton of carbon dioxide. This cost is still huge for this technology to be cost-effectively practicable. Explicitly, removing 1 gigatons of carbon would be $ 260 billion, and the world generates 32.3 gigatons for each year of carbon in energy production only. If the carbon capture system reduces the energy loads in its system, creating a market for the captured compressed carbon granules, and achieving a total cost of $ 60 / ton of carbon dioxide or less, this technology may be very efficacious. Inappropriately, it is presently very expensive to use for the architectural project [16].

4.1.1.3. The remedial performance of the direct carbon capture system

This system can currently capture carbon dioxide and carbon monoxide by 80%, so it is possible to purify the air by 1.3 tons of carbon per day. These ratios look good, if the energy and cost are directly controlled for the feasibility of the project. There are currently no information or data that indicates the ability of this system to capture pollutants other than carbon derivatives in the air [17].

4.1.2. Second system: Closed system biofiltration

Biofiltration systems were extensively employed for more than 40 years in the United States and Europe to control odors and volatile organic compounds in wastewater treatment spaces, animal husbandry spaces, fertilization facilities, and other low-concentration pollution production processes. Throughout the last few years, it has been increasingly employed in North America to treat air pollution streams in large and low concentrations. Studies are currently underway to investigate the suitability of the biofiltration system for pollution emissions control applications and try to adopt them in the external and internal facades of open-yard projects such as malls, airports and others to treat air pollution. Biofilters are prominent channels within the facades or construction that contain organic materials found in most farms, such as peat (leftover olive oil after extracting it), wood chips, organic fertilizer mixed with sand, floor textures (highly porous synthetic fibers), plastic parts or very small glass to filter air pollutants. The layers are arranged and compressed successively, forming a biological layer consisting of microorganisms. Polluted air is humidified through a humidifier and pumped into the biological filter throughout a chamber under the filter. As the air gradually flows up through the filter media, the pollutants are absorbed into the air stream and metabolized by microorganisms, where they then emit clean oxygen as a by-product. Then, the filtered air passes from the top of the biological filter to the atmosphere outside the building in the case of the external facades and into the building in the case of the interior facades [18].

4.1.2.1. Closed biofiltration system operation

Closed biofiltration systems offer very high efficiencies in filtering polluted air, they take up less space and are highly economical. These systems consist of vertical containers containing channels or media. The multi-layer system averts the compression of the filter media and supports eliminating of the risk of emission of steam or humidified air by compressing the contaminated air stream drawn into the filter (emission occurs when gaps are formed in the biological membrane, allowing pollutants to pass through without filtering).
In addition, media surfaces or layers allow comfortable upkeep as it is the time to alter filter layers. The pollutants in the air are spread perpendicular to the direction of the flow, and decompose in the biofilm layers. Since the filtration process is controlled by gradual diffusion, scheming a huge distance among biofilm layers reduces the total decomposing rate in the filter. Nevertheless, further distances as well mean that the biofilms in the biofiltration filter must remain moist to maintain vital activity.

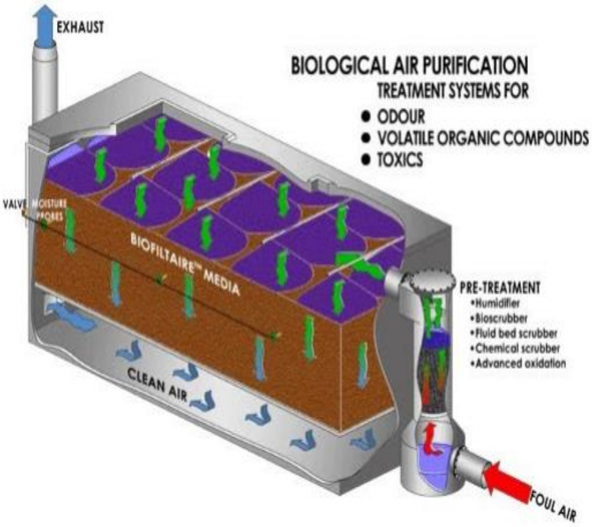

Figure 2. Example of a closed biofitration system based on Ottawa Library atrium Interior design based on https://inspire555.ca/library-archives-spaces/

The air flowing over the biofiltration filter pulls moisture away from the biofilms, so the air incoming to the system should be constantly moistened to keep the moisture and nutrients flowing into the effective bacteria in the biofilms. Thereby oxygen is released as a by-product of the filtration process [19].

4.1.2.2. Design flexibility of closed biofiltration system

The most part of the closed biofiltration system consists of tanks having filter media, and the fan system represents the moisturizing element that feeds the media with contaminated air. These two components are not essentially designed close to each other, allowing the architectural designer to control the design and orientation of systems. The filters can be placed inside containers that can be prepared for resembling rocks, creating them a feature of landscapes. The tops of the filter surfaces (from which clean air will be depleted) can be fill with soil and plants, making a garden and inserting to the air filtration efficiency.
Biofiltration units can be considered to suit any outline or size, making them somewhat adjustable. This means that they are highly flexible with the aesthetic formation that serves the design [20].

4.1.2.3. The cost of a closed air filtration system

Biofilters present a distinctive set of benefits as compared to other air filtration technologies based on cost-effectiveness. Costs involve materials, fans, power consumption, air ducts, full body, and labor for construction. The typical cost of constructing and connecting a biofilter in a mechanical system is approximately $ 275 per 1,000 cubic feet for each minute of projected airflow rate. This equals approximately $ 16.60 per kilogram of treated air. The expenses of building and upholding a biological filter will be differed depending on the preferred amounts of air to be filtered (and, as a consequence, the size of the filter system), but as compared to other air filtering techniques, the biofilters are very cost-effective [21].

4.1.2.4. Remedial performance of a closed biofiltration system

In addition to the low cost of this system, the biofiltration is multipurpose in its capability to process odors, poisonous complexes and volatile organic compounds with efficiency ranging from 70-90%. Volatile organic compounds resulting from vehicle emissions are usually filtered at 16 grams per cubic foot for each hour, or 13.6 kg for each cubic meter for each day. Ethanol, toluene, ammonia, and other emissions have been filtered at about 24,000 cubic meters per day. As for other pollutants, the biological filters are able to filter nitrogen oxide and sulfur oxide pollutants. After a series of tests conducted by the California Environmental Protection Agency. It has been found that the efficiency has been about 20%, and extract about 0.012 g for each cubic meter per minute, or 6.3 kg / m 3 / year. However, at what time the scholars entered a fungal nitrogen removal organism to a biofilter, there has been a significant increasing in NOx consumption to approach 90%. This increased nitrogen oxide consumption to 8786 kg / m3 / year or 24.1 kg / m3 / day 44.
Biofiltration proves to be highly in effect in industrialized environments and in the filtering of volatile organic compounds. Nevertheless, it is ineffectual in adjusting carbon dioxide, and needs fungal nitrogen removal organisms with the intention of filtering nitrogen oxides. Consequently, biofiltration is less efficient in air pollution and in addressing climate changing as compared with other systems [22].

4.1.3. Third system: Titanium dioxide technology (smog corrosion interfaces)

The applications of titanium dioxide technology in architecture depend on the potentials inside the materials that have been discovered and activated to produce materials with new properties and capabilities. This adds to the devices' technology and equipment that have been developed at a high speed. Titanium dioxide was used in the field of architecture to help in sustainability; providing the architectural designer a new way of thinking to address pollution. Therefore, the application affecting the science of architecture falls into two main parts, which are the materials and devices involved in building or operating. The technology enables titanium dioxide to work inside the molecules of the material to improve its properties and gain tremendous potential to contain applications that it did not have before. In this way, it gains more than the capabilities of one substance at the same time. This helps the architect to overcome design and operational restrictions and add a new material to the sustainable medium to address the smog resulting from vehicle exhaust, and factory and plant emissions.

4.1.3.1. Smog and its components

Smog is formed when pollution levels in the air rise, and this leads to health problems; most notably those in the respiratory system. Smoke (smoke + fog = smog) consists of several substances such as ozone gas and nitrogen dioxide. Burning fuels are the main source of smog components, such as vehicle exhaust and manufacturing activities in industrial facilities, factories, and plants.

Smog is currently a major problem in many countries of the world, such as China. In Beijing, many people are forced to wear face masks when leaving the house. The Chinese government is trying to reduce the problem by enacting legislation that reduces emissions of pollutants such as banning the use of coal as fuel.
Ozone gas is a molecule consisting of three atoms of oxygen. In the case of smog, it is formed in the lower parts of the atmosphere near the surface of the earth as a result of the interaction between pollutants emitted from vehicles and factories in the presence of sunlight. Ozone gas formed in this way is known as bad ozone according to the US Environmental Protection Agency [23].

This type of ozone gas is called "harmful" to distinguish it from another type called "good ozone", and it has the same molecular structure (O_3). However, it is formed in the upper atmosphere at altitudes ranging from 16 to 48 kilometers. Useful ozone forms a layer that protects living things from ultraviolet radiation that reaches with the sun's rays. It absorbs them and prevents them from reaching the surface of the earth. Ultraviolet radiation rays play a major role in increasing the risk of human skin cancer.
Nitrogen oxides such as nitrogen monoxide and nitrogen dioxide, are produced by industrial activities, fossil fuel combustion processes, and power plants.

Sulfur dioxide is resulting from industrial processes and oil refineries.
Particulate matter is a mixture of very small particles and liquid droplets produced from forest fires, volcanoes and fossil fuel burning processes such as coal and oil. Materials with a diameter of 10 micrometer or less pose a health threat, as they can be inhaled to enter through the throat and nose into the lung.

4.1.3.2. Titanium dioxide technology

Titanium dioxide technology filters the air polluted with smog through the building's façade. There are projects that prove their ability to filter air pollutants for (10,000) vehicles per day from the building's perimeter through a reactive material that stimulates with sunlight to purify the air from these pollutants. But how does that happen? Titanium dioxide (TiO_2) is a reactive material stirred by sunlight that transforms air pollutants as in nitrogen oxides (NO_x), volatile organic compounds (VOCs), carbon monoxide (CO) and ozone into biologically tolerable products like carbon monoxide and calcium nitrate. These materials can be treated either via [24]:

- Mixing it with the concrete, so that the concrete mixture becomes pollution absorber
- Mixing it with specific polymers to produce facades designs
- Mixing it with asphalt
- Using it as a façade paint
- Or a transparent layer for the surfaces

This innovative technology was recently applied in Manuel Gea González Hospital in Mexico City, which is one of the most polluted cities in the world, by the Italian Pavilion Project of the Expo Milano Exhibition Group (Italy Pavilion – Milan Expo 2015).

4.1.3.3. The first project: Manuel Gea González hospital in Mexico City

Prosolve370e units were used to cover the entire façade, which is a three-dimensional collectible decorative architectural unit that removes air pollutants by applications (Optical stimulation technology by titanium dioxide TIO_2). The units are characterized by ease of installation, assembly, and flexibility of formation, and are also used in [24]:

- Combating air pollutants, the ability to eliminate the pollutants of 8750 vehicles per day
- Anti-fog spreading in the city
- Reducing wind speeds to treat the most air pollutants possible
- Take advantage of all aspects of the façade (skin)
- Shading the building to maintain low temperatures
- Reduce building thermal loads
- Distinguished mental image of the building

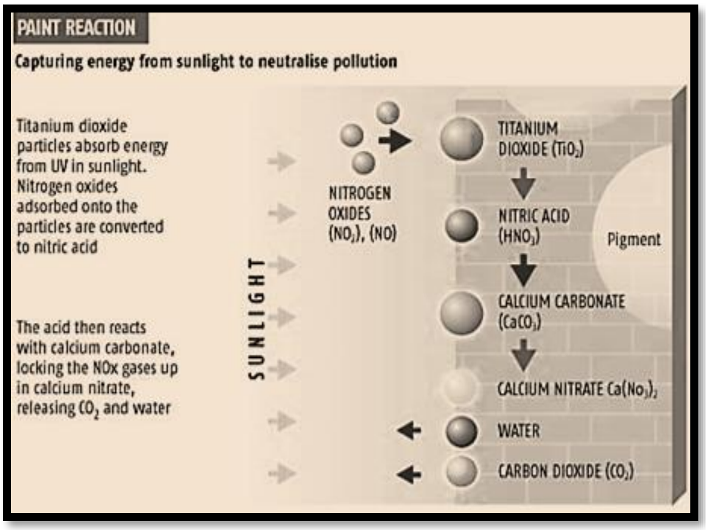

Figure 3. Oxygen activation by Titanium Dioxide diagram designed by a German team of designers from Elegant Embellishments

It combines the function of capturing polluted particles and aesthetics. 90% of the façade (about 2,500 square meters) is covered with a vertical metal structure that contains about 500 blocks assembled like a puzzle. Each block consists of five units. Inscriptions increase the absorption in surface and reduce wind speed. They also generate disturbances that better distribute polluted particles to the surface of the units. Since each piece of the façade has multiple patterns, polluted particles can be picked from different directions. Units do not require heavy machinery to be installed. The pieces are attached to massive slabs on the ground and subsequently fastened to a vertical grille on the front.

Figure 4. Manuel Gea González Hospital in Mexico City

Technology of titanium dioxide has been applied to parts (units) of the façade through modern devices linked to the Rhino program (the program through which the main units were designed for the façade) to implement the shapes of the interface. The shapes are transferred and removed to the covering sides which, in turn, make ready-made molds according to the given dimensions. These molds are active titanium dioxide. Afterwards, the pre-made parts of prosolve370e are wrapped with covering molds of the photocatalytic technology and air pollutants treatment [25].

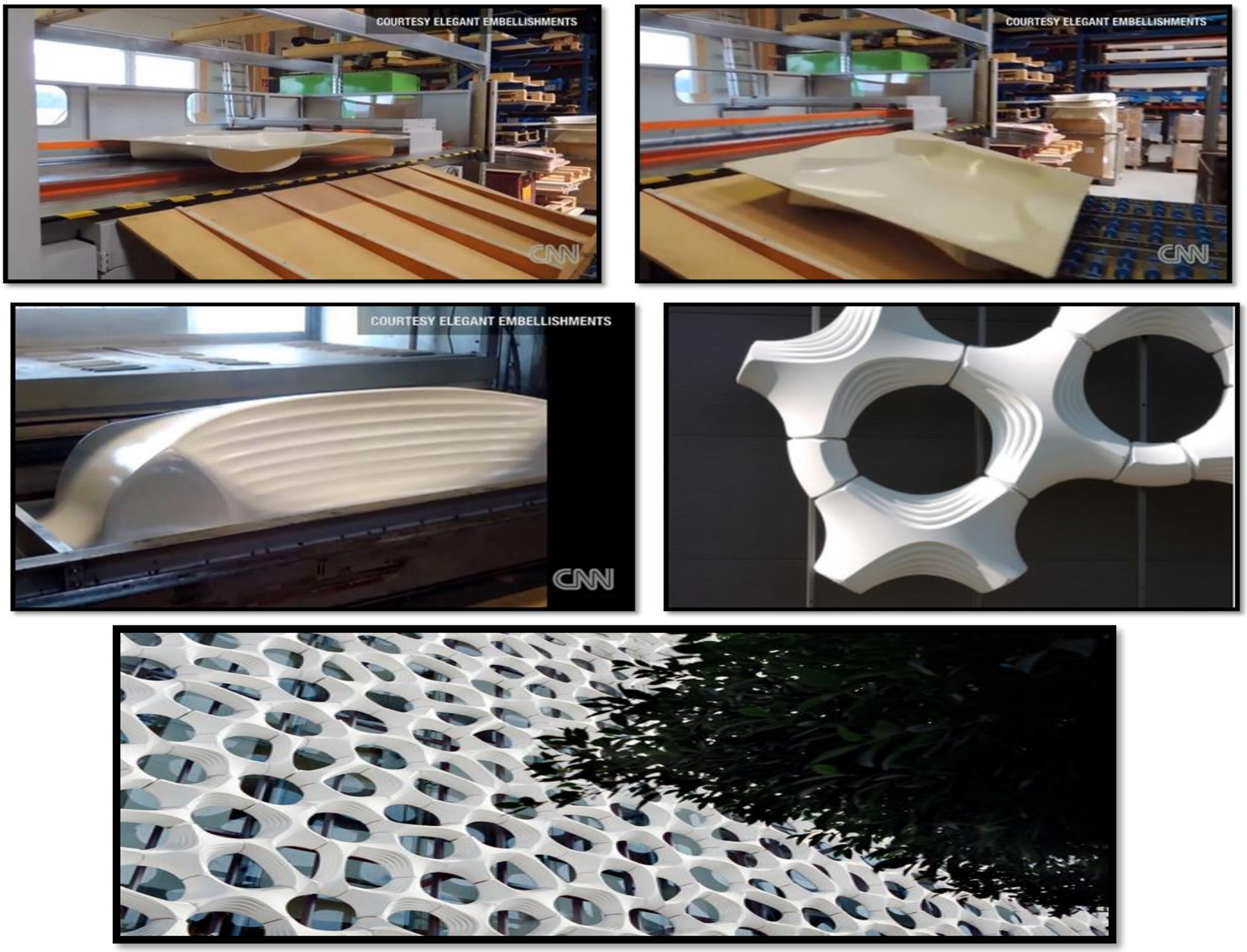

Figure 5. CNN investigation on Mexico's smog eating building [25]

4.1.3.4. The second project: Italian pavilion of Milan Expo Group

The merging of design, technology, and sustainability led to good results, as in the Italian Pavilion project. A global competition was held for Expo 2015, through which among the 68 competitors, the first prize was awarded to Nemesi, Proger and BMS for engineering works and Prof. Eng. Livio De Santoli for sustainability business.

Figure 6. Pictures by Nemisi studio about "Italy Pavilion Expo 2015” [26]

The Italian Pavilion consists of the permanent building Palazzo Italia (Italy Palace) 6 floors with a built-up area of 14,398 square meters, and temporary buildings (Cardo) on two floors with a built-up area of 12,551 square meters. Palazzo Italia is 35 meters high, thus being the highest within the site. The project is considered a difficult architectural and constructional challenge due to the complexity and innovation in the design, and materials and technologies used. This building is designed according to the principles of sustainability. This is attributed to the properties of photovoltaic in the ceiling glass and photocatalytic in the concrete which is new of its kind for the branched façade. 2000 tons of i.active biodynamic cement were used, covering about 700 branches, all of which are different, covering an area of 4,000 square meters. Thereby forming a sailing cover for the building and consuming 400 tons of steel to install the façade pieces.

Figure 7. Pictures by Nemisi studio reported in YouTube under the name "Italy Pavilion Expo 2015"

As for the design of Nemesi, the main idea of the project was "Urban Forest" which was represented through the branched structure that encloses the building as represented by the façade. For its design, Nemesi created a unique engineering texture that evokes intertwined random branches, as in tree branches. The outer façade is covered with more than 700 sheets of biodynamic cement produced by Styl - Comp and Italcement, patented in active titanium dioxide technology. When this material comes into contact with light, it can catch pollution in the air and turn it into inert salts which reduces fog levels in the air. The innovative ceiling was achieved by Stahlbau Pichler to act as a simulation for the forest's shadow. This ceiling, with optoelectronic glass and curved and simple engineering shapes together with the manifold structure, is a clear expression of innovation in design and technology [26].

Figure 8. Images of Italy Pavilion Expo 2015 [26]

Through the technology of titanium dioxide, a mixture of plastic, cement, and titanium dioxide was reached to form pre-made hard plates that are easy to work and configure. They are subject to the ideas of the architectural designer. The facades are designed through modern programs and then divided into several numbered sections, making ready molds for each numbered section of the façade, and then the process of casting molds begins. After completion, the pieces are attached to a huge steel structure to form the main façade.

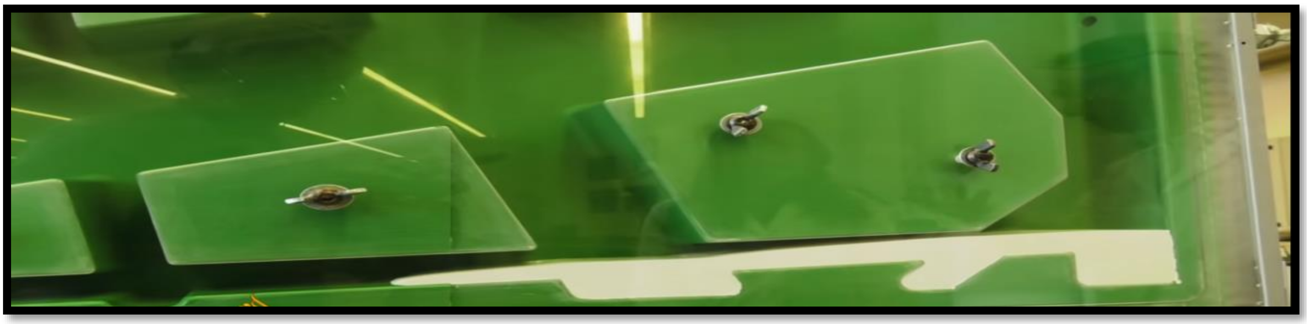

Figure 9. Italy pollution-eating cement-earthrise [27]

Following the impressive success of the Italy Pavilion - Milan Expo project and the ability of its facades to treat smoke equivalent to 10,000 vehicles per day, Nemesi, Proger and BMS presented a pilot project to cover a third of Milan with the active titanium dioxide technology subject to photocatalysis. Covering third of the city's buildings with this material enables it to treat the pollution in vehicle exhausts to approximately 60% of daily air pollution.

A huge laboratory has been opened in Italy with multiple branches under the name "SENINI" adopting the optical stimulation technology of active titanium dioxide. This is made for the production of facades wrapping tiles, as well as floors, tiles, exterior and interior coatings, and concrete. There is a high percentage of demand on these materials in health building projects, hospitals, and resort buildings in order to provide a clean and healthy environment around the buildings [27].

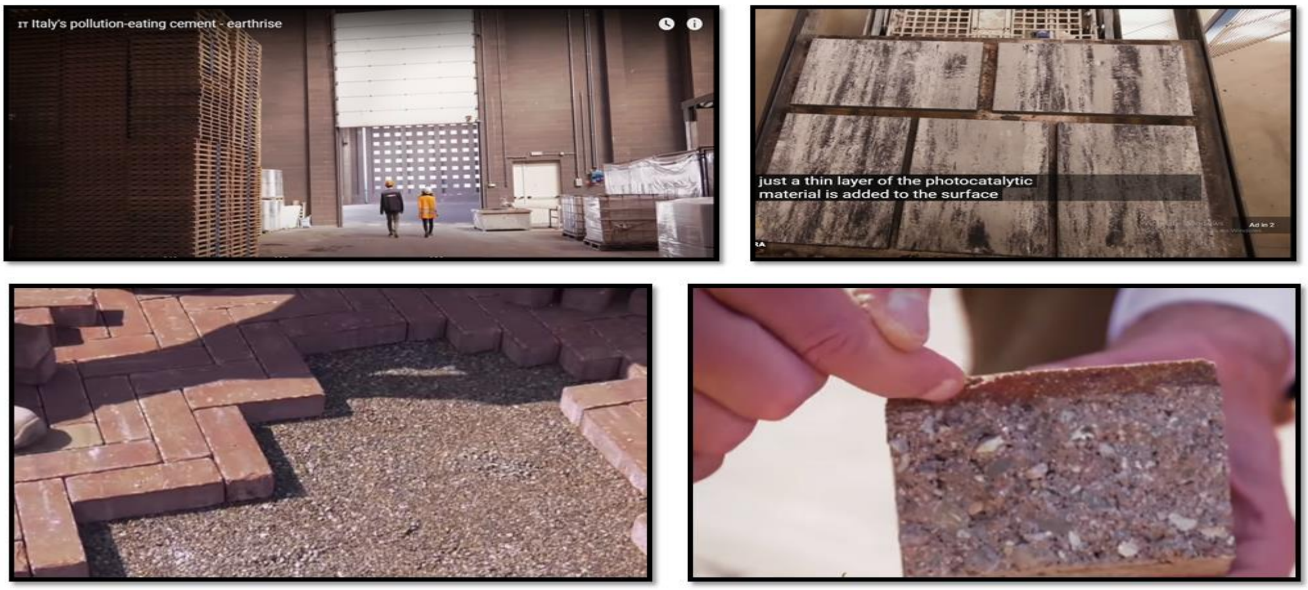

Figure 10. Other instances of "Italy pollution-eating cement-earthrise" [27]

4.1.3.5. Cost of titanium dioxide technology

This pollution-treating system is considered to be a very economic system equivalent to $ 2.20 per square meter for covering surfaces. With additional labor costs, the total price becomes $ 8.30 per square meter, but if it is added to concrete or asphalt, there will be an additional cost of 4%. In addition, the technology of photocatalysis through active titanium dioxide reduces the building's level of gaining solar heat, which means a decrease in the use of electricity for cooling in the summer. This is due to utilizing sunlight which will be reflected by titanium dioxide, consequently resulting in an annual net energy saving equivalent to 20 - 30% of total energy [28][29].

5. Conclusions

The research diagnosed a serious problem represented by air pollution generated by vehicle exhaust and suggested systems used in some models for controlling air pollution through buildings adapted to the natural environment. The necessity of working with sustainable design, considering that the philosophy of sustainable design is a conscious philosophy. This philosophy revolves around designing material objects, constructed environment and services in accordance with the principles of economic, environmental and social sustainability alongside its cultural and spiritual values. Sustainable design is environmentally conscious design, in all its propositions, which makes the constructed environment less harmful to the natural environment. Sustainable design seeks harmony with nature with its propositions and orientations. At the beginning of its propositions, attention was focused on the economy and circulation of energies and resources, and then it focused on design values that seek to address human health and performance within the building, especially after diagnosing the appearance of sick buildings. Recently, sustainable design propositions began to seek to activate the positive impact of the environment on human well-being and health through studying natural systems and their impact. Thereby putting into light, the concept of sustainable green design towards fundamental human values (nature-loving design).

The concept of ecology is a broad concept associated with sustainable design as a broad design philosophy based on the balance of the resources flowing among the elements of the ecosystem. The design is perceived as a simulation of natural systems in their circulation of energy and material among its elements; leaving no side remnants of waste or pollution. Therefore, all propositions concerned with simulating models derived from natural ecological systems fall under the umbrella of sustainable ecological design with the aim of reaching environmental treatments that help nature cure itself from pollution.

Sustainable design is linked to pollution treatment technology as a system of inter-effect between internal and external design elements. The concept of self – healing building is associated with sustainable design technology as an approach that seeks to reduce the negative impact on the environment according to the system of addressing external pollution between the elements to achieve environmental health and economic vitality.

Pollution eating by building façade is a new concept concerned with technological systems that provide a healthy environment treated from pollution not only for building users but also the surrounding environment. Some types of these systems can address pollution resulting from smog for 10,000 vehicles per day. There are three technological systems to treat pollution through the building's facades. The adoption of these facades makes the building appear as a living organism in its contribution to treating the environment in addition to providing fresh air for its occupants. These three systems are:

1. Direct Carbon Capture Technology
2. Closed Air Filtration Technology
3. Titanium Dioxide Technology

In spite of the efficiency of these systems and their economic return to the building through the production of pure carbon dioxide granules, titanium dioxide technology has proven its worth in many projects on the aesthetic and economic level and its efficiency in air purification from pollutants.

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