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Controlling Air Pollution with the Use of Bio Facades
(A solution to Control Air Pollution in Tehran)

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Abstract

Statement of the problem: The speed with which cities develop cause disruptions to the environment and create problems such as air pollution. Air pollution management programs are often focused on controlling the sources that are producing the pollutants. This method can effectively reduce the level of new air pollutants but it is does not have any effect on existing pollutants that are already in the air.

This paper, by accepting the current state is looking to control air pollution in order to reduce the level of harm to humans through architecture, municipal engineering, and the effect of facade structures. The capabilities that nature itself has in controlling air pollution have entered the field of architecture. Three of these capabilities will be studied: water facades, algae facades and green live facades.

Purpose: One of the most important approaches in architecture and municipal engineering is paying attention to nature as a model and solution to environmental problems. The main purpose of this research is to have a better understanding of how bio-based walls promote air quality and reduce pollutants and how to create a more productive bio-facade.

Research method: Because this research is interdisciplinary, combinative methods need to be used in order in undertake this research. The majority of the resources for this paper have been through libraries and available references; however, in order to further expand there is a need for combining the research from interdisciplinary fields. Because there is a lack of quantitative data about each system's performance, the systems will be introduced through tables and their strengths and weaknesses will be identified. The research will then be applied to practical methods, which will allow for the qualitative comparison of these systems. The most productive method will be chosen.

Conclusion: Based on all stages of this paper, and by considering the qualitative comparison of 3 bio-based facades and studying each system's strengths and weaknesses, it should be acknowledged that green facades, can present a suitable structure for controlling Tehran's air pollution. In regards to plans and predictions of Tehran's municipality about beautification, it should be acknowledged that green facades have a higher chance for short-term productivity in solving this problem in the capital.

Keywords: *Air pollution, Bio Facade, Algae, Watery Facade, Green Wall.*

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Introduction and statement of the problem

Air is one of the five essential elements (air, water, food, heat and light) for humanities survival. Each person breathes about 22,000 times a day and needs almost 15 kilograms of air in a day. Usually humans can survive without food for 5 weeks and without water for 5 days, but they cannot survive without air for even 5 minutes.

Air pollution directly impacts air quality. Air pollution is the existence of one or more pollutants in open air with particular features and constancy, enough for jeopardizing the life of humans, plants, and animals or human properties or disrupt the right and desirable process of life in a significant way (Peavy & Chupanuglus, 1999: 10). One of the most important issues about this discussion is predicting the dispersion and density of pollutants in different places. This is very important because it can help in recognizing different pollutants and the center of their accumulation and as a result, detecting sensitive and vulnerable points and also for predicting necessary actions in order to prevent these kinds of problems (Heidari Nasab, 2013).

Scientific research in the last two decades show that existing pollutants in the air should be considered as the main danger for mankind's health from the public health point of view. City air usually contains a significant amount of pollutants, which can jeopardize human health (Mayer, 1999). The World Health Organization estimates that 500,000 people a year, are facing an early death because of interacting with floating airborne particles in the air. Furthermore, this organization estimates that 6 percent of all deaths are a result of air pollution (Krzyzanowski, 2008).

Therefore, confronting air pollution is one of the main concerns for nations and governments. A lot of organizations and institutions are dealing with this problem so that they can solve it. Although it has been a long time that mankind has understood the importance of the environment in their lives, it has been the last decades of the 20th century that have peaked in proposing environmental issues. Today, environmental problems have posed a big danger to mankind not only because it is disrupting their comfort and safety, but also because it is threatening their existence. The issue of environmental pollution is not a problem for only one country or territory, but it is a problem for the whole world which consists of different issues and the most important of them being water and air pollution.

Like many other big cities of the world, Tehran is one of most polluted capitals in the world. In Tehran, more than 1,200-ton pollutants are spreading in the air on a daily basis. This is while the rate of carbon dioxide dispersion is growing more than 22 percent a year in the country. Both the direct and indirect effects of air pollution pose a dangerous threat to the health of the city's inhabitants. Based on the last report from the World Health Organization, air pollution is the fifth cause of human death. Epidemiology studies on Tehran's air pollution, next to many other big cities in the world, show that from every 10 deaths in Iran, 1 death is due to air pollution. This paper is seeking to find how urban architecture and design can confront this problem. Architecture through sustainable development seeks to promote life quality by reducing energy consumption and air pollution (Mofidi Shemirani & Madani, 2007).

One of the most important approaches in architecture and urban engineering is paying attention to nature as a model and solution for modifying environmental problems, which in this paper is presenting bio-based facades as a way to control and reduce air pollution.

Theoretical Foundations

•Research Background

Air pollution was involved with human being from the very first time they created fire. By looking at the definitions of air quality in old references, it can be seen that pollution and purification discussion were also proposed in the past. For example, in the third chapter of Zakhireye Khwarazmshahi's third book, this definition is given as air quality: "Of course air has a particular quality and…. this air which people are breathing is not pure enough. But it is mixed with

smoke, steam and dust and besides that, it takes its quality from other qualities and from season to season in a year, its quality changes… and a well-quality air needs to be pure and free of toxic" (Jurjani, 1946).

Even though today air pollution is known as a modern problem, its issues related to quality, dates back to the old days when people burnt wood in big cities and used them in industry and handicraft.

Later on in big cities, despite the fact that coal and steel were the two indicator of wealth, the smoke that came from the burning coal, created a public health problem and because of that, so many people left so many cities during those years. The first major change in air pollution discussion was raised before industrial production in 13th and 14th centuries. After the industrial revolution, air pollution story started a new procedure which the main cause of these dilemmas were the usage of fossil fuel and greenhouse gas.

In history of dealing with air pollution, there are evidences based on the existence of social campaigns for confronting air pollution which was one of the primary campaigns against the approval and implementation of laws for controlling smoke in Chicago Cincinnati in 1881. Of course the implementation of this law and similar laws were faced with many difficulties, however, the approval of similar laws in next years continued until today and was brought up more seriously in national and international communities. In table 1, you can see some recent activities and events that were held under supervision of environmental protection agency (Kovarik, 2018).

In Iran the first step for confronting air pollution was taken and an "environmental health agency and controlling air pollution" was established in health engineering administration office in 1996. In 1969, an international seminar was held in Tehran for dealing with air pollution with the presence of world health organization representatives. This process continued

Table 1. Events and actions of United Nation for controlling air pollution in recent years. Source: Kovarik, 2018.

1990	Clean air law about Sulfur oxide and Nitrogen oxide dissemination is reformed in power stations Bush government suggest the law of "clean sky" to reforming congress of clean air law (the main law of federal for air quality)
2003	United states Senate working on circumstances for making the way clear in order to make clean air law, practical.
2004	Scientists' researches show that air pollution can damage children's lungs.
2009	United States, announce new declaration about clean air law for reducing the dissemination of greenhouse gases from power stations.
2011	Legislation laws was constituted for extracting power installations in The United States which approved the regulations of air quality and bring up the issue of shutting down two tenth of the power stations.
2012	Air pollution law is blocked in United States. One Federal board of judges, targeted environmental protection agency law by the belief that existence of air pollution is passing the established lines of the government.
2013	Air pollution in north of China, through the unlimited use of coal caused 500 million citizens in north China lose their life expectancy for more than 2.5 billion years.
2015	President Obama carries out an environmental plan for confronting with air pollution and putting it on top of plans for dealing with climate change by International agency of environmental protection's clean energy plan. This plan is basically limited to greenhouse gas dissemination from oil and coal. India's government says that air pollution in the last 9 years has killed 35000 people. Researchers believe that air pollution reduces people's life span up to 3 years in India. But none of these brought up any serious action until today.
2016	International Energy agency says that deaths caused by air pollution is still increasing and if current policies do not stop the pollution, this procedure will go on.
2017	Donald Trump cancels a compulsive instruction which reduces air pollution and greenhouse gas regulations.Maryland and many other States will be reprimanded because of not executing the clean air law regulations.

with so many ups and downs (Ghasemi, 2001). Until after so many years of delay in Iran, the general bill (law) of clean air was approved by members of parliament in October 2016.

But the most important thing in this research is a background for paying attention to the subject of controlling bio-base facades particularly for air pollution. Fulfilled studies, do not show a footrace of any particular research with this title, although in each parts of watery facades, algae facades (recent background) and green facades (older background), there are few evidences on some previous researches which we will get to each one of them.

Research questions

This research is done based on this general question: "How are the impacts of bio-façade on reducing air pollution in urban and architecture areas?" In other words, how can these levels have an affective role on making biological comfort in urban areas?

As it was mentioned in previous chapters, air pollution issues and alternatives for confronting it, is not a new problem and it goes back to hundreds of years ago. But the significant point is that, most of these studies, researches, suggested alternatives, and approved regulations, didn't follow up the issue of controlling air pollution radically and they just discussed it through controlling pollutant's resources. However, what this paper is following is the acceptance of existent situation and presenting alternatives for controlling these pollutions. The questions which this paper is based on are as below:

-Do nature and architecture have a role in controlling air pollution discussion?

-What types of bio-facades can control the air pollution?

-Which facades are productive for Tehran among air pollution preventive bio-facades?

Research hypothesis

According to research questions, the main hypothesis of this research is expressible in two sentences:

-Bio-based facades are effective in achieving urban comfort by reducing air pollution.

-Green walls are a proper alternative for reducing Tehran's air pollution.

Reasons that can be named for testing the accuracy before entering research are:

1.Nature has always been the right answer to human and environments' needs.

2.Green areas have a significant role in controlling air pollution

Research requirements

What is happening in most cities such as Tehran is jeopardizing citizen's quality of life in urban areas and also reducing their existence in cities. The increasing air pollution is an issue which is threatening city's quality in a serious way and it is facing a lot of challenges. This issue can explain the necessity of these researches which are looking for alternatives in order to solve this problem.

Cities that are dealing with air pollution problems should look for a proper solution in order to control this problem and reduce its consequences. Air pollution controlling plans are mostly focused on controlling pollutants and production resources (Schnelle & Brown, 2002). This alternative can significantly reduce the level of new pollutants in the air, but it doesn't have any effect on pollutants that are already in the air.

Even though "controlling polluted resource" approach is looking for a cure in a more comprehensive way, but it is a long-term and expensive plan. And the number of effective variables is so much and during all these years, it hasn't reached any significant results. But in this paper, by accepting air pollution as a dilemma and controlling it as a necessity, some alternatives will be represented for controlling these pollutants in order to reduce the level of damage to humans.

Research method

Since the purpose of this paper is focused on representing alternatives for reducing air pollution effects by bio-based facades, and due to the fact that "most of architecture researches are interdisciplinary and need a combination

of particular methods" (Wang & Grut, 2009), therefore, despite most studies, this paper is based on library method and reading available references, but the expansion of this research needs a combinative research in interdisciplinary fields. Due to the lack of quantitative data about each system's performance, after introducing systems and identifying their weaknesses and strengths by tables, the research has been done by a practical method and qualitative comparing systems and the most productive method that will be chosen (Fig. 1).

Discussion

• The idea of architectural bio-based facades for controlling air pollution

Architecture can have a positive or negative effect on the productivity of building's energy and also it can improve the quality of air effectively. Scattered researches with different titles, which have been done in different countries is a proof of this point. But the facades which have the ability of controlling air pollution are not limited to bio-facades that are the purpose of this study and it also includes other structures like some kind of materials with Nano technology. All in all, the main focus of this paper is on facades based on nature. Nature accountability in solving human issues has been proved to be working all along. Human and environment survival depends on preservation and constancy of balance in environmental world.

Increasing progress in the growth of scientific specialties in modern era from one side and the recognition of nature's ability from another side brings up so many new perspectives for researchers and designers. This view, rather than representing elegances and mysteries of nature's system, is an opportunity for achieving so much success in an environmental persistence.

In this paper nature's capabilities in air pollution control the discussion, enters architecture field and these alternatives will be reviewed in 3 titles as "Watery facades", "algae facades" and "green and alive facades".

Using water in building's façade

The pattern for using water in building's façade comes from air cleansing by rain. When it rains, nature helps create a mechanism for eliminating pollutants in the shape of rain drops in which atmospheric pollutant's gases will be absorbed and solid particles will fall as rain drops (Shukla, Misra & Sundar Shyam, 2007).

In the case of using water for building's façade for controlling air pollution, two ideas will be represented: "water spraying on facades" and "watery curtain".

a)Water spraying idea

Water spraying idea was followed up in China and India, more than any other country. The two countries which allocate 55 percent of the deaths from air pollution in the world (Fig. 2).

In December 2017 in New Delhi, they tried an "anti-pollution gun" for reducing air pollution which a

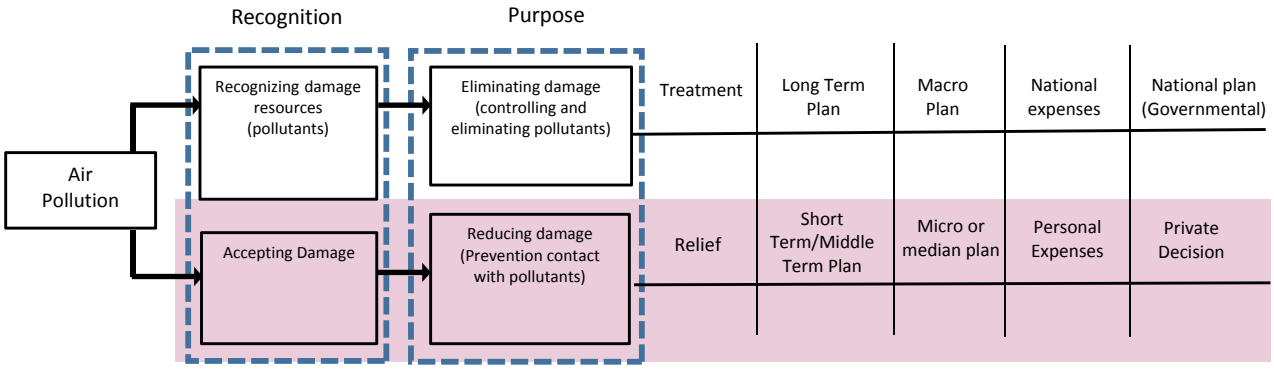

Fig.1. Explaining the course of confronting air pollution topic in the paper. Source: author.

spraying machine pours water in the air to 230 feet. The purpose of this move was merging water drops with dust particles which has a similar effect as rain

Fig. 2. Spraying water in Delhi air. Source: CNN,2017.

for reducing air pollution.

Before this action, the idea of water spraying for reducing air pollution was represented in a more scientific way in China's communities. This suggestion was brought up by Shaocai Yu, that water spraying in atmosphere from tall towers and big buildings is explained as similar to garden irrigation. In this paper which was published in Springer environment chemistry publication, Yu explained this procedure as a new approach to preventation of heavy dust and air pollution (Fig. 3).

Yu considers water spraying to atmosphere of earth as a simulation for natural rain which can effectively eliminate and collect aerosol and gas pollutants.

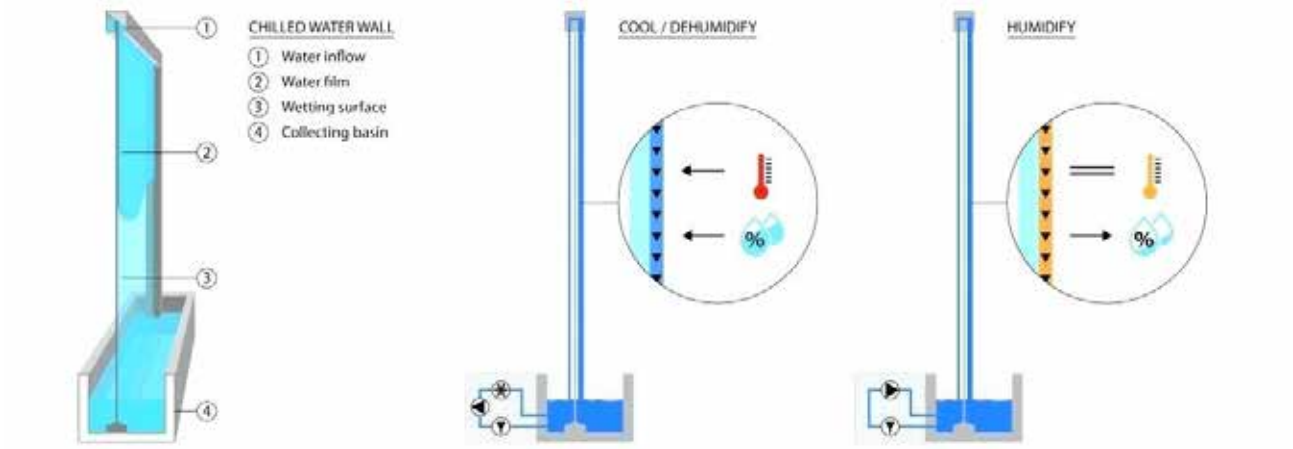

Fig.3. A representation of a watery wall details. Source: Fraunhofer Institute, 2018.

Also, other chemicals can be added to water spraying for other purposes (Shaocai, 2014).

b)Watery facades

Another alternative is using water for controlling air pollution and using a layer of water on façade (mainly as second facade) as a filter towards pollutants.

One sample in using watery curtain for façade is Hydro Place building in Manitoba which has Canada's LEED certificate. The biological-environmental design and the observance of optimization principles in this building is the main reason of its reputation. This new building has an affordable structure with efficiency and progress in the field of energy which indicates its commitment to sustainable development. (Hume, 2009).

Comparing to ordinary buildings which use the natural air circulation, the air in Hydro Place's buildings as its constructors say, is 100% fresh and healthy regardless of the air temperature during the 24 hours of the day. Inside two towers, there is a collection of southern apartments or winter gardens which constitute the lungs of the building and before the exterior air enters building space, it can be filtered by adjustable gates in balcony's floor. Depending on the season, a tall waterfall by adjusting humidity can be effective in order to access fresh air from

entry air. Accessing fresh air is the main purpose of using this waterfall in building's façade which besides cleaning air can adjust entry air's humidity before its distribution in atrium. (Kuwabara, Auer, Gouldsborough, Akerstream & Klym, 2009); (Fig. 4). Each thread of watery façade is a unique 4-millimeter strap from firm and thin polyester which by strap's weight can put them on lower part tension so that water flow can control each thread and provide maximum amount of air flow by penetrating in watery facades. Façade's water temperature is adjusted regarding the thermal converter by building's management system and according to relative humidity of inner spaces. The available water in this facade will retake by close system and the level of threading and water overflowing depends on season and atmospheric situation. By using a pomp with sensitivity to pollutants, water will operate by a reverse filtering

A B C

Fig.4. A) Details of water façade in Hydro Place building in Manitoba (Hydro Place Manitoba site) B) Digital water curtain in Poland museum C) Water wall in Anderson hospital. Source:

system to eliminate particles.

Using watery walls and curtains, besides being practical for sublimating air and eliminating pollutants, is designed and used in many projects by emphasizing on its aesthetics aspects. And in some models this system is incorporated with digital approaches.

Algae façade

In contemporary architecture and in urban buildings, the popularity of glass spaces is still continuing for aesthetics reasons. However environmental effects of using glass facades bring up some concerns due to heat's severe drop and undesired hot weather increase. Algae live systems is proposed as a sustain alternative which can synthesize a bioreactor alga in a glass façade. Algae façade can provide light transmission and as a porter wall it can replace current glass systems with proper thermal and structural function. Algae façade is designed for improving air quality in environment by producing oxygen and absorbing CO_2 through algae's photosynthesis. (Snijders & Bilow, 2013).

Bioreactor system is placed between two acrylic papers and algae are growing in a rich liquid full of nutrients. This container is designed in a way that it can present a good energy and structural function. Through this facade, there is a possibility for observing daily light and ventilation. Fig. 5, demonstrates the general façade and operation mechanism of an algae's façade system.

Studies about using algae in architecture is happening in many cases. In GSA proposal plan algaes are being used for wastewater filtration and diffusion absorption of CO_2 next to highways. Its second purpose is to produce Lipids which can turn into biofuel. (Fig. 6- A). Another concept project is urban farm in the polluted city of Tehran which is represented by EcoLogic studio (Fig. 6- B). This Project also used a photo bioreactor pipe which provides a cooling system for the building by the effect of its shadow.

But BIQ apartment is the first built model in the world based on this idea which uses algae façade as a purifier. (Fig. 6- C). Algae façade panels in this building, prevents the entrance of too much sunlight and heat into the building and with the use of an environmental reactor, it will turn this energy to a useable biomass (Kyoung, 2013).

Algae is turning to a new term in environmental architecture so quickly. Some institutions are making

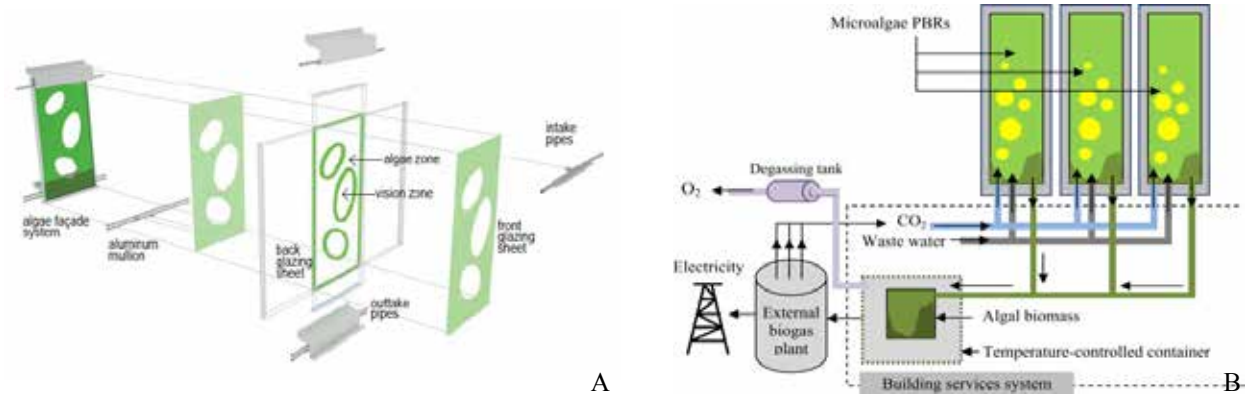

Fig. 5. A) demonstration of an algae façade's components. B) Operation mechanism of algae façade. Source: Elrayies, 2018.

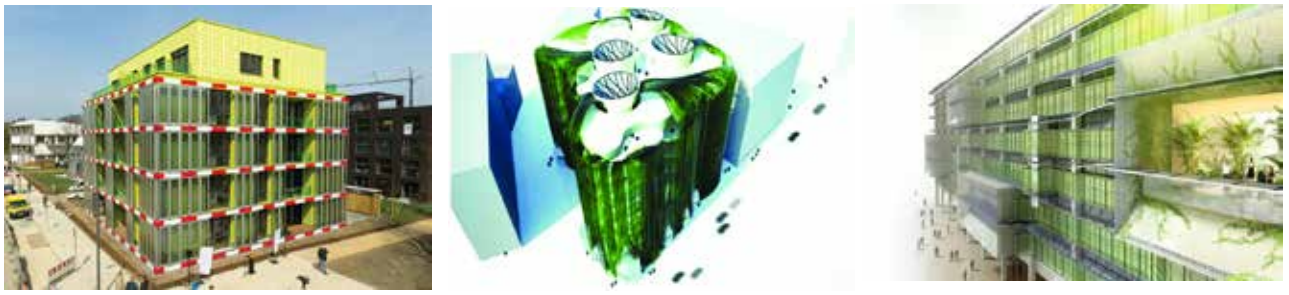

Fig.6. A) GSI building algae façade B) Tehran city farm concept project C) BIQ algae building. Source: Kyoung, 2013.

investments on projects based on algae and this subject is considered as an alternative for solving problems regarding sustainable installations. Algae besides having the capability of producing hydrogen and biomass, it can also diagnose pollution and absorb carbon dioxide while releasing oxygen.

Green algae sustainable plan is being followed up with a forwarding approach in Chicago Central Area Action plan. Natural absorption capability of CO_2 is being followed up and urban sustainable development in 20th century's towers is also being reviewed. This project is a close ring system which focuses on 3 different levels of reducing carbon: Direct carbon absorption from air, plant photosynthesis absorption and other installations with natural use of energy.

While, the world is looking for a replacement for fossil

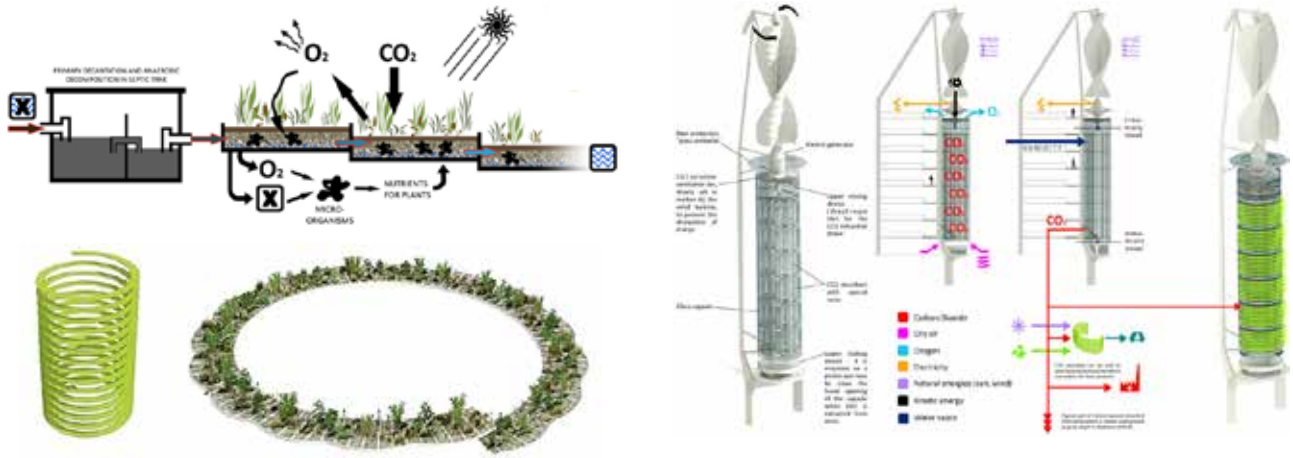

Fig.7. The diagram of the shape and function of the green algal ring in the Chicago Central Area Action Plan. Source: Influx Studio, 2011.

fuel, algae are unlimited source of energy, food and more important a natural absorptive of CO_2.

Green Facades

The use of plants in small and large scales can have significant effects on air pollution. UNEP in paragraph 9 ("21 Articles about the 21st century") of its report discusses the need to sustain urban spaces, and the greening of urban spaces as one of the possible solutions for achieving greater sustainability in the cities. It should be noted that although trees can be very effective in reducing air pollution, planting trees in densely populated cities is not always easy (Yang,Yu & Gong, 2008). Green facades can be an appropriate alternative and provide the necessary green spaces earlier mentioned to achieve sustainability in urban spaces.

Green facades are a good technology to create an environment free of pollution (Thottathil, et al, 2010). These walls are capable of filtering toxic gases, suspended particles in air and other contaminants. The surfaces of leaves absorb dust, pollen, and filters toxic gases. Filtration is carried out by plants and through microorganisms (GreenRoofs, 2008). This idea, also known as living architecture, uses plant growth on building surfaces to improve air quality and control the severity of rainwater. (Perini et al, 2012).

There are many benefits to green facades, but this article focuses on air purification. However, it should be mentioned that the construction of these green facades has some challenges, both of which are presented in Table 2.

In a more fundamental approach, it is better to replace the generic term of green facades with the term vertical green facades. Green facades should be seen as one of the subsets of vertical systems. By accepting this, vertical green systems can be categorized into three broad categories of green facades, green wall covers, and living walls.

Each of the above categories can be further divided into two parts, each of which is described in Table 3 below (Azmoude, 2016).

By comparing vertical green systems, it can be argued

Table 2. Benefits and Challenges of Green Walls. Source: author.

Benefits of green walls	Increasing the weather quality Reducing the thermal island effect Visual beauty Psychological improvement of the city's residents Ecological value Reduction of greenhouse gases Reduction of noise pollution Increasing the weather quality	**Challenges of green walls**	Installation and maintenance fee Creating an ecosystem for insects Increasing the weight of the building Increasing moisture in the space

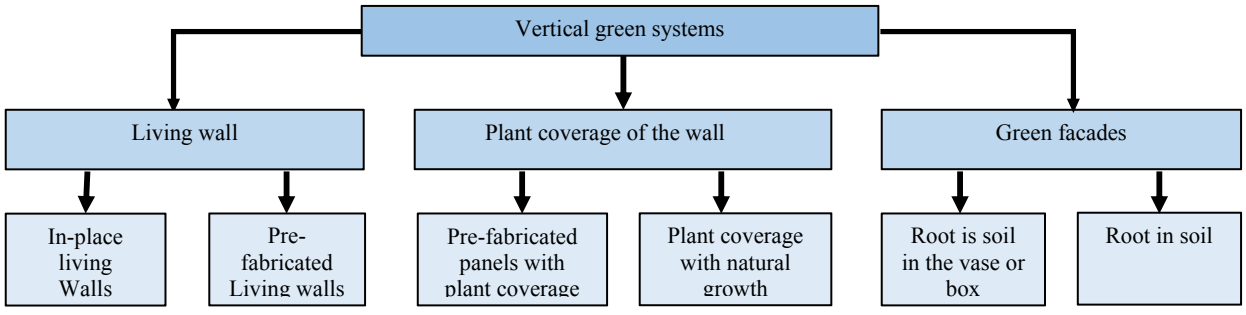

Fig. 8. Classification of green vertical systems. Source: author.

Table 3. Various types of vertical green systems. Source: author.

Green facades	Root in the soil: Here, plants go on the wall naturally without using the supportive structures. In these types of green walls, it usually takes a long time for the plant to cover the whole surface of the wall.	
	Root in the vase or box: In this type, plants grow from the vases with a medium size. An irrigation system is always needed for this group, since the root of the plants are not directly in the ground soil.	
Green wall cover	**Green cover with natural growth:** This type is usually seen on old walls, walls of the gardens, and the buildings of historical cities. They grow irregularly without human intervention.	 
	Premade panels with green cover: The green walls of this group use concrete panels. This is a very recent system. These panels have pores between the pebbles, which are filled with soil and provide the possibility of growth. Only a few plant species are able to grow in these concrete substrates.	
Living walls	**Premade living walls:** This system is made up of premade panels or Integrated fabric which are attached to a frame or structural wall. The walls made by this system are able to support a variety of plants. Boxes and geotextile sacks are used in this type. These boxes are attached to a buffer and sometimes can be attached to a wall structure.	
	In-place living walls: They are semi-prepared systems, which can be attached to façade. After installing wool layers, plants can be placed in the box. Due to the determined capacity of boxes, plants cannot grow unlimitedly. It should be noted that this system cannot be used for the plants with thick roots.	

that responsive systems for controlling air pollution that can respond on an inclusive scale include both types of green facades (roots in soil and roots from a potted plant) and pre-fabricated living walls. Among them, the living wall produces results in a short time and can be used on a larger scale; hence this paper focuses on living walls.

In this regard, pre-fabricated living walls are composed of vertical restraint systems, moving boxes, geotextile bags, soil and plants. The plant species that are used on the living wall are selected based on the light and ambient temperature of the location in which the wall is

going to be installed.

Comparison of Bio-based Layers and Achieving an Optimal System in Tehran

In the previous sections of this paper, three bio-facades were introduced, and the characteristics of each were described. In summary of the above-mentioned issues, the advantages and disadvantages of the three systems are presented in the following tables for achieving the proposed optimal facade (Table 4).

By examining the strengths and weaknesses of the three systems with a reverse approach to the subject, a qualitative comparison can be made

Table 4. Strengths and weaknesses of three bio-based layers. Source: author.

Water-based facades		
	Strengths	Weaknesses
Climate aspects	• Creating sub-climates • Reducing the effect of heat islands • Cooling the weather • Increasing humidity	• Impossibility of using it in all climates • Inconsistency and identical function in all seasons • Limited effect radius
Financial aspects	• Reducing the costs resulting from air pollution • Increasing the value in the market • The duration of usage • Easy repair and maintenance	• Increasing the water cost • Increasing the maintenance cost of the main facade
Architecture and structure aspects	• Ameliorating the beauty of the city • Creating lighting effect due to reflection • Not cutting the visual connection of inside and outside • Not applying heavy load on the façade	• It is not a physical barrier per se • Possibility of damage to façade due to existence of salt.
Environmental aspects	• Absorption and filtering of polluters • Ameliorating the air • Improving atmospheric conditions and creating sub-climates • Managing rain water	• Absorbing insects • Possibility of water freezing in cold seasons
Stability aspects	• Less energy consumption • Reducing façade temperature • Increasing living space • Increasing life quality	• Increasing water consumption • Need to insulate the main facade • Not controlling the sound

Algae facades		
	Strengths	Weaknesses
Climate aspects	• Creating sub-climates	• Lack of suitable functioning in all climates
Financial aspects	• Increasing value in the market	• Higher cost of creation (due to lack of technology in the country) • Requiring experts for repair and maintenance
Architecture and structure aspects	• Possibility of using it as loading wall • Beautifying the wall • Creating penumbra effect due to reflection	• Increasing the weight of the building • Obstructing the visual structure
Environmental aspects	• Filtering pollutants • CO2 absorption • Increasing air quality • Managing rain water	•
Stability aspects	• Reducing energy consumption • Rapid biomass production • Increasing life quality • Sound insulation • Motivating governmental and non-governmental organizations to conduct studies on algae	• Lack of knowledge about algae facades • Lack of technology availability

Green facades		
	Strengths	Weaknesses
Climate aspects	• Creating sub-climates • Reducing the heat island effect	• Impossibility of applying it in all climates • Inconsistency and not functioning in a similar manner in all seasons • Limitations in terms of plant selection in different climates
Financial aspects	• Reducing the cost of energy for cooling • Reducing the costs resulting from air pollution • Easy repair and maintenance	• Lack of knowledge about the financial benefits • Higher costs of building • Higher water consumption
Architecture and structure aspects	• Increasing plant coverage in private areas • Efficient use of façade • Ameliorating scenery of the city • Increasing the design of green spaces in the city	• Requiring suitable structural metrics • Requiring structural strengthening to apply the green wall • Creating visual distraction due to changing of the colors of plants in different seasons
Environmental aspects	• Reviving the green space of the city • Absorption and filtering of the pollutants • Creating wild life in the city • Cleaning the air • Improving atmospheric conditions and increasing the cleanness of air • Purifying the weather and creating sub-climates • Managing rain water	• Possibility of making bad smell • Possibility of making allergy for some people • Absorbing insects
Stability aspects	• Noise reduction • Reducing energy consumption • Reducing façade temperature • Cooperation of citizens in making green spaces • Increasing living area • Improving life quality	• Lack of knowledge on the benefits of green walls • Possibility of being damaged by people

between the three building layers. The overall benefits of these layers are not overlooked, but what is important is a comparison of these values and whether the implementation of these facades is possible. This comparison is based on the five climates, the economy, architecture and structures, the environment, and sustainability as seen in the table below.

When generally assessing the three types of bio-based facades, it should be mentioned that there is a lack of sufficient experience in the field of algae cultivation in the country. In addition, algae cultivation is a new movement and there is a lack of knowledge about how algae will preform on a facade. At the moment this option is not optimal for mass use in Tehran despite its strengths. Furthermore, the unfamiliarity of the public with this subject is likely to result in a lack of general acceptance in the short term.

However, in the case of water and green living walls, they may be used in combination or separately in building facades. However, the use of water facades is not a possible option at present because of the high cost of water, the shortage of water in the country, and the minerals in the water have damaging effects. Therefore, if we have to choose between

water and green facades, considering the plans of Tehran's municipality regarding beautification and increasing the amount of green space per capita points to green facades. In addition, the relative familiarity of this category to the public means that the green facade has a greater chance in the short run (Table 5).

Green walls are considered one of the new approaches to architecture and urbanism, which is based on the concepts of sustainable development in order to increase per capita green space, improve environmental quality, and sustainable urban development. The results of previous studies indicate that the green space in some areas of Tehran is below international standards. Therefore, applying green wall technology can be one of the most effective compensatory measures in reducing environmental hazards in densely populated areas

Table 5. Comparison of bio-based layers. Source: author.

climatic comparisons			
	Watery shell	**Algae facade**	**Green Living wall**
Usable climate	Hot and dry	Hot	Hot and dry
Location of the façade	All facades	Sunshiny	Sunshiny

Economic comparison			
	Watery shell	**Algae facade**	**Green Living wall**
Façade life-time	Unlimited	-	15-25 years
Building cost	Relatively low	High (due to lack of technology in the country)	High
Utilization period	Low	Moderate	Moderate (dependent on plant type)
Repair and maintenance	Easy – Requiring periodic control	Requiring experts	Requiring periodic control
Increasing value in the market	High	High (Due to innovation in the façade)	High

Architectural and structural comparison			
	Watery shell	**Algae facade**	**Green Living wall**
Aesthetics	Positive	Relativity positive	Positive
Façade operation (Internal and external obstruction)	Not a physical obstruction per se	Yes	Yes (dependent on type of the green wall)
Light passage	Yes	A little	No
Visual connection of the inside and outside	Yes	A little	No
Increasing building weight	A little	Yes	Yes
Load support	No	Yes	No

Environmental comparison			
	Watery shell	**Algae facade**	**Green Living wall**
Improving air quality inside	Yes	Yes	In some systems
Improving air quality outside	Yes	Yes	Yes
Moisture control	Increasing moisture level (desirable)	Increasing moisture level (Sometimes undesirable)	Increasing moisture (Sometimes undersirable)
Rain water management	Possible	Unpredicted	Possible
Improving public health	Yes	Yes	Yes
Compatible with climatic change	No	No	yes

Sustainability comparison			
	Watery shell	**Algae facade**	**Green Living wall**
Heat control	Yes – cooling effect of air	Yes	Yes
Requiring insulation of the façade	If it is in front of main façade, insulation is required	No	Yes
Noise insulation	Very low	Yes	Yes
Resistance to wind	No	Yes	Yes (relatively)
Urban climate balance	Yes	Yes	yes

of Tehran (Taghavi, 2014), and can reduce air pollution.

Conclusion

The main objective of this study was to provide a better understanding of how bio-based walls interact with each other to improve the quality and remove pollutants from the air. The lack of quantitative data on the each system's performance is an issue that should be considered in future research. But according to all the steps taken in this paper and in accordance with the preceding tables, it can be admitted that green walls can provide an optimal structure in this regard.

In viewing each of the bio-based layers against the current conditions in Tehran, what is important is the achievement of a productive and timely solution. Algae facades, despite their high capabilities are not a good solution for today's state, because it is a newer and unfamiliar technology. In the case of water facades, the issue of water scarcity in the country, and especially in Tehran, cancels out the use of this option in current circumstances.

Although a review of the comparisons show that the green wall is not an optimal solution in all areas, but based on the previously explained points and according to the capabilities of the country at the moment, it is the most suitable choice. The use of green facades in urban spaces in Tehran can noticeably reduce the presence of pollutants in the air on a small scale.

The costs of installing and maintaining these walls are very high and the level with which they reduce cooling and heating costs inside the building is not considered very notable or efficient. However, by considering the reduction of air pollution in sub-climates, the relative reduction of the temperature in hot seasons and hours, and improving the sub-climate around the wall, green walls can be one of the effective options for improving the climate of Tehran on a small scale.

Based on the approval of the Tehran Municipality Air Pollution Reduction Task Force regarding

the increase of green spaces per capita, the green facade can partly compensate for the current pollution problems. Green facades, being a sustainable option, are a solution that reduces energy consumption, reduces consumption costs, creates natural beauty, and improves the quality of the climate. Green facade technology is progressing, and designers are implementing new and different projects every day. However, in our country, and particularly in Tehran, the potential of such facades have not been used sufficiently and is not accepted as a standard component in buildings. Hence, more research is needed to improve the quality of architecture in terms of protecting the environment, and taking advantage of its capabilities in creating sustainable architecture.

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