Environmental Protection Solutions for Heritage Buildings from Air Pollution Impacts "Case-Study of Qasr El-Manial, Cairo, Egypt"

GEHAN NAGY, KHALID DEWIDAR, MONA AZOUZ, MARIAN NESSIM, DINA SALEM, YASMINE SABRY, FAYROUZ ASHRAF
Architecture Department,
The British University in Egypt, Housing & Building National Research center, Zagazig University,
El Sherouk City, Misr Ismailia Road, Cairo,
EGYPT

Abstract: - The current local strategies are reactive in response to risk or damage, usually in the form of treatments, repairs and retrofitting on the building scale, there is a need for proactive strategies that rely on preventive conservation concepts which can be more sustainable and cost effective as it minimizes the possibility of deterioration and risk through controlling its cause on different scales. In order to conserve historic buildings from deterioration caused by air pollution, the impact of air pollution on these buildings need specification and quantification in order to control below the tolerable thresholds using convenient strategies on the appropriate scale. The main objective is to minimize deterioration of Historic Buildings caused by Air Pollution through the development of a framework for local management preservation strategies. A survey conducted to validate the framework. This will lead to types of preventions (UNESCO PRECOMOS Chair) as follows; primary prevention by avoiding the causes of the unwanted effect (damage), secondary prevention as the means of monitoring that allow an early detection of the symptoms of the unwanted effects, and tertiary prevention that allow avoiding further spread of the unwanted effect or the generation of new unwanted (side) effects.

Keywords: - Management strategies; Preventive conservation; Historic buildings; Air pollution

Received: May 11, 2022. Revised: October 4, 2022. Accepted: November 12, 2022. Published: December 29, 2022.

1 Introduction

Environmental problems caused by air pollution in Cairo are resulted from particulate matter, sulfur dioxide and lead existing in elevated levels. Also, the sources of air pollution include vehicle emissions, rubbish burning and industrial wastes [1]. The degradation of the exterior and interior surfaces of historical buildings, whether classified as monuments, historic buildings, or sites, are to a great extent affected by air pollution [2]. The visual appearance on the architectural facades in the terms of discoloration to yellow or black, and the deteriorated situation of the buildings caused by the chemical compounds and particulate matters that settle on the surface [3]. The impacts resulted would extend and appear for a lengthy period of time, as the impacts would be irreplaceable [2].

This paper will present a chosen case study of Qasr El-Manial palace with analytical study on applying mitigation strategies to diminish air pollution impacts on the palace. The methodology used is qualitative analysis through literature review and on-hands workshop, and quantitative analysis through applying mitigation strategies on the case study and presenting a map of highest scoring strategies.

2 Types of Air Pollutants

Air pollution is one of the main reasons that lead to economic loss of heritage buildings. Deterioration of materials are as a result of atmospheric impact such as temperature, moisture, sunlight, and wind movement. The deterioration caused to materials by air pollutants are as the following processes [4]:

- Corrosion
- Abrasion
- Direct and indirect chemical attack
- Deposition and removal

2.1 Sulphur Dioxide SO_2

Sulphur dioxide, a corrosive gas produced from chemical industries, is considered the most air pollutant responsible for the corrosion of metals. The reaction of SO_2 with the atmosphere results in acid rain. It causes deterioration of materials not only metals but also marble structures and buildings throughout the years as the amount of SO_2 increases in the atmosphere [4]. SO_2 impacts the deterioration of carbonate rocks the most. Gypsum created on the surface of the rocks. A pollutant usually accumulates on surfaces of buildings in dry and wet matter. The accumulation of dry deposition influenced by variation into the atmosphere and chemical features of pollutant types. The SO_2 accumulation on material surfaces depends on factors such as relative humidity, buffer acid capacity and humid surface. This process can vary by two different effects. The first factor depends on the natural structure of materials, wind speed, humid surface, and pollution concentration. As for the second factor, it depends on the chemical activity and the moisture content of the surface. The cause of temperature differences by moisture, sunshine and a warm breeze affect the most on SO_2 accumulation [5].

Fig. 1: Effect of SO_2 on heritage buildings [5]

2.2 Nitrogen Dioxide NO_2

The process of burning of fossil fuels produces nitrogen oxides which also results in acid rain when reacted with the atmosphere [4]. Nitrogen oxides damage effects are more observed than SO_2 due to the high solvability of calcium nitrate which is easily removed from surfaces regularly. The oxides in nitrogen compounds differ from that in sulfur compounds, therefore relative concentrations of nitrogen change on a daily cycle. In an environment involving water, the oxidation of NO_x results in the creation of nitric acid HNO_3 as a secondary type. The most important type of nitrogen that plays an act in deterioration of rocks is nitric acid HNO_3 found in the atmosphere, but it is difficult to measure it in a daily manner. HNO_3 produced as photochemical on the marble and calcareous rocks. The effect of nitric acid is the most aggressive compared to other nitrates on the deterioration of historic surface materials [5].

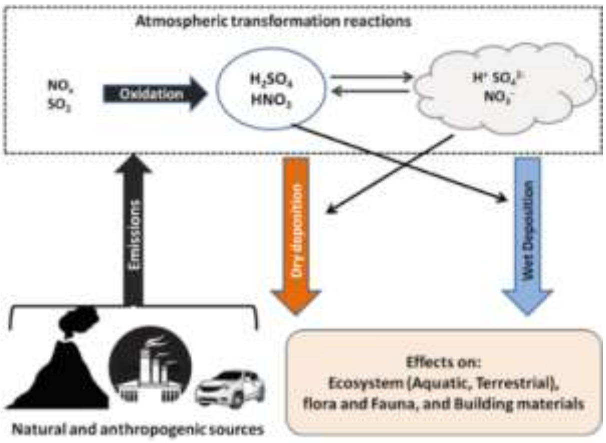

Fig. 2: Process involved in the acid rain [6]

2.3 Carbon Monoxide CO

Major air pollutants as SO_x, NO_x, and CO are a result of the combustion of fuels emitted to the atmosphere. However, the smoke of urban air and exhaust fumes from fossil fuels are the main sources of carbon monoxide CO. The emission from these sources causes severe damages to structures especially to those located near factories and industries [4].

Fig. 3: Colour contrast of building surfaces affected by CO [4]

2.4 Particulate Matter (PM)

Particulate matter has an abrasive nature causing damage to buildings' surfaces when driven at high velocities by wind. It comes in the form of fumes, dust and soot creating a layer on buildings surfaces. The process of corrosion of metals such as steel, copper, and zinc accelerated by the corrosiveness of particulates or in the existence of SO_2 and moisture [4].

Fig. 4: Discoloration of the Taj Mahal [4]

2.5 Ground-level Ozone O_3

The weathering of materials such as fabrics and rubber caused by the ozone. The ozone, considered as a reactive substance, is found in two layers of the atmosphere; the lower layer is the troposphere and the other is the stratosphere. The part of ozone in the troposphere is more hazardous than the stratosphere. On the other hand, ozone in stratosphere protects the earth from harmful ultraviolet radiation which also protects buildings' structures [4].

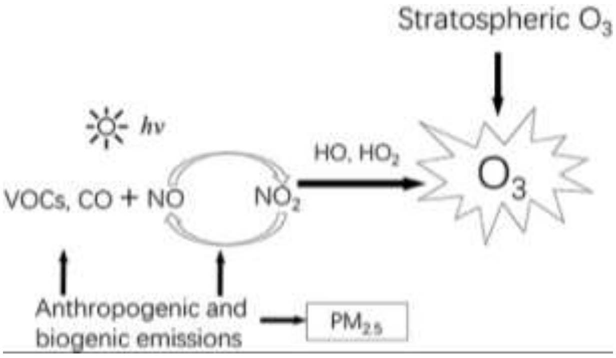

Fig. 5: Formation of ground-level ozone O_3 [7]

3 Mitigation Strategies on Urban Scale

There are three main strategies on mitigating air pollution on an urban scale as mentioned below.

3.1 Reduce (Reducing Emissions)

The 'Reduce' strategy depends on reducing pollution without direct intervention to the receptor from the source of pollution. Low Emission Zones (LEZ) and Zero Emission zones (ZEZ) applied in this strategy along with introducing alternative means of transportation such as electric vehicles, cycling, and buses. Also, pedestrian areas are considered with limited to no traffic entry in certain areas and defined times.

3.2 Extend (Extending Distance)

The aim of the 'Extend' strategy is to use passive methods to maximize the distance between sources and receptors with either solid or porous barriers. These barriers will lead to air pollutants dispersion and deposition. It can be in the form of low boundary walls, parked cars, and vegetation in different forms. The use of technology and air quality monitoring networks could be involved in this strategy.

3.3 Protect (Protect Receptors)

The 'Protect' strategy depends on using direct interventions that involve green infrastructure and green walls to reduce the concentration of air pollutants at the receptor's site.

3.4 On-hands Workshop Discussions

A workshop conducted with the participation of different experts and entities to discuss results of how to apply the proposed mitigation strategies on Qasr El-Manial palace. The following table contains the output from 8-groups, each group has a variety of different specialties.

Table 1. Highlight points from roundtables discussion sessions

Group-1	▪ Add vegetation around the palace's outer premises to protect the walls from exterior pollution, as the palace is protected from the inside by the walls. ▪ Add parking lots far away from the palace.

Group -2	▪ Detour the entrances and exits leading to the palace. ▪ Add parking lots at the entrance of the street away from the palace's premises ▪ Use HEPA filters on the hospital chimney that is located near the palace. ▪ Use concrete blocks that have the ability to absorb CO_2 and filter the air. ▪ Create buffer zones to function as wind breakers. ▪ Add pedestrian roads around the palace. ▪ Green roofs on buildings around the palace. ▪ Adjust the vegetation inside the palace detouring the air flow to create wind deflection from the palace ▪ Allow electric cars in the area close to the palace.
Group-3	▪ The original library of the vegetation existed in the palace reviewed to ensure restoring the heritage value. ▪ Similar cases analysis study. ▪ Recommendations from stakeholders should consider pollution from interior and exterior factors. ▪ Restore all original features with different technological solutions without harsh interventions to the inner premises of the palace.
Group -4	▪ Create a GIS model to count the number of cars around the area to measure pollutants resulting from them to set the suitable number of cars to pass daily. ▪ Shift to electric cars.
Group -5	▪ Resolve the causes rather than propose solutions. ▪ Categorize each cause resolved and integrated with the action plan
Group -6	▪ "Planning" should be added to the three strategies proposed: "Reduce-Extend-Protect" ▪ Planning should also introduce: ○ Plan of planning ○ Action plan to the mitigation ○ Regulations must be set ○ Overall plan to the process
Group -7	There should be more criteria added to the mitigation strategies proposed such as studying land uses of the surrounding area.
Group -8	How to protect the building from any factors that can affect the palace even without interventions of any exterior criteria such as vegetation or traffic.

3.5 Applied Strategies from Workshop Discussion

Below is the output resulting from the workshop discussions in relation to the three mitigation strategies "Reduce-Extend-Protect."

Table 2. Scoring of mitigation strategies applied on the case study

Workshop groups	Reduce													
	Low Emission Zones	Zero Emission Zones	Electric vehicles	Cycling	Walking	Limiting entry	Speed limits	Bus lanes	Pedestrian areas	Traffic circulation	Ultra-Low Emission streets	No internal combustion vehicles	Speed management	Less polluting vehicles
G-1	○	○	×	×	○	○	○	×	○	✓	-	○	○	○
G-2	○	○	✓	○	✓	○	×	×	✓	✓	-	○	×	○
G-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
G-4	○	○	✓	-	-	✓	○	-	○	✓	-	○	✓	✓
G-5	-	-	-	-	-	-	-	-	-	○	-	-	○	○
G-6	-	-	×	×	×	×	×	×	×	○	○	×	○	×
G-7	-	-	○	○	○	○	○	○	○	○	○	-	○	-
G-8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scoring %	**37.5**	**37.5**	**37.5**	**25**	**37.5**	**50**	**37.5**	**12.5**	**50**	**75**	**25**	**37.5**	**62.5**	**50**

Workshop groups	Extend							Protect					
	Passive methods	Vegetation	Linear green infrastructure	Remove traffic-related pollutant	Application of technologies	Air quality monitoring networks	Reduce humidity by plants	Reduce concentrations	Green infrastructure	Aerodynamics roughness	limited maintenance & fast-growing plant	Intervention in terms of G14AQ	Green walls in street canyons
G-1	○	✓	○	○	×	×	○	○	✓	×	○	○	○
G-2	○	○	✓	○	✓	×	○	✓	○	✓	○	✓	✓
G-3	✓	○	○	×	✓	✓	×	○	○	○	○	○	○
G-4	-	-	-	○	✓	✓	-	✓	-	-	-	-	-
G-5	✓	-	-	-	○	○	-	-	-	-	-	-	-
G-6	○	×	○	○	○	✓	×	○	-	-	-	○	-
G-7	-	-	-	✓	-	✓	-	-	○	○	-	-	-
G-8	✓	-	-	✓	✓	✓	-	✓	-	○	-	-	○
Scoring %	75	**37.5**	**50**	75	75	75	25	75	**50**	**50**	**37.5**	**50**	**50**

(✓) properly implemented, (○) partially implemented, (×) not implemented, (-) information not available

4 Case Study: Qasr El-Manial Palace

4.1 History of the Palace

Prince Muhammed Ali's palace or Qasr El-Manial is located at El-Manial district, Cairo. The prince designed the palace's unique architecture by himself. It consists of seven buildings, they are the reception hall, the clock tower, the mosque, hunting museum, residence hall, the throne hall, and the private museum, surrounded by a prestigious garden planted with rare and indigenous species of plants and trees from various parts of the world [8].

Fig. 6: Qasr El-Manial interior premises

Fig. 7: Vegetation in Qasr El-Manial

4.2 Qasr El-Manial Surrounding Environment

The following map presents the sources of pollution that affect the palace and cause deterioration to its exterior walls, the palace's buildings, and interior premises.

Fig. 8: Map indicating sources of pollution around Qasr El-Manial palace

Table 3. Sources of pollution around Qasr El-Manial Palace

1	Cairo University Bridge	
2	Qasr Al-Ainy air quality monitoring station	
3	The main street in front of the palace with high traffic density	
4	Roundabout that leads to the palace	
5	Gas station beside the palace next to the roundabout	
6	Al-Manial Specialized University Hospital	
7	The chimney of Al-Qasr Al-Ainy Hospital	
8	Garbage thrown near the palace's walls	
9	Car parking close to the palace's walls	
10 & 11	Heavy congestion in the parking spaces on the side street of the palace	
12	Car maintenance center in front of the sidewall of the palace	
13	The high humidity appears on the walls of the palace	
14	Restaurant in the back street of the palace	

5 Conclusion

The mitigation strategies applied are according to the most scored strategies deduced from the workshop outcome as the following:

- The 'Reduce' strategy applied using traffic circulation which could in detouring traffic directions leading to the palace and removing any parking cars close to the palace's walls, while creating far parking lots for visitors. Applied strategy by removing any source of pollution from administrative buildings in the surrounding area.
- The 'Extend' strategy applied using passive methods such as prohibiting throwing garbage near the palace and adding vegetation barriers. Also, remove any traffic related pollutants such as car maintenance centers around the palace, gas stations that

are congested by diesel and fuel cars. Technologies used include HEPA filters on surrounding chimneys that affect the palace as well as make use of air quality monitoring networks near the palace.

- The ‘Protect’ strategy applied as in reducing concentrations of air pollutants affecting the palace such as humidity.

Table 4. Concluded strategies applied on Qasr El-Manial

REDUCE		Traffic Circulation
EXTEND		Passive methods
		Remove traffic-related pollutant
		Application of technologies
		Air quality monitoring networks
PROTECT		Reduce concentrations

In conclusion, the map below presents the mitigation strategies dealing with each pollution source surrounding Qasr El-Manial Palace.

Fig. 9: Map presenting applied mitigation strategies on pollution sources surrounding Qasr El-Manial Palace.

Acknowledgement:

The paper is part of a research project (ID: 41601), a collaboration between The British University in Egypt, Housing and Building Research Centre, and Zagazig University, funded by Science and Technology Development Fund (STDF).

References:

[1] N. Rovella, N. Aly, V. Comite, L. Randazzo, P. Fermo, D. Barca, M. A. d. Buergo and M. F. L. Russa, "The environmental impact of air pollution on the built heritage of historic Cairo (Egypt)," *Science of the Total Environement*, vol. 764, 2021.

[2] P. Kumar and B. Imam, "Footprints of air pollution and changing environment on the sustainability of built infrastructure," in *Science of the total environment*, vol. 444, 2013, pp. 85-101.

[3] A. Hernández, "Impact of environmental pollution in the historical buildings of Havana, Cuba. Effect of future climate change," *Revista Ingeniería de Construcción,* pp. 127-136, 2018.

[4] N. V. Rao, D. C. Rao and M. Rajasekhar, "Detrimental effect of air pollution, corrosion on building materials," *American Journal of Engineering Research*, pp. 359-364, 2014.

[5] S. Tirink, Y. A. Argun, Z. Bingül and A. Altıkat, "Negative Impacts of Air Pollution on Historical-Cutural Structures," in *INTERNATIONAL ENERGY & ENGINEERING CONFERENCE 2016 (UEMK 2016)*, 2016.

[6] S. Sonwani and V. Maurya, "Impact of air pollution on the environment and economy Sonwani S, Maurya V," in *Air Pollution: Sources, Impacts and Controls*, Oxford, CABI Publisher, 2018.

[7] J. Zhang, Yongjie and Z. Fang, "Ozone Pollution: A major Health Hazard Worldwide," *frontiers in Immunology*, 2019.

[8] Egyptian Ministry of Culture, The Glory of Islamic architecture, Historic Cairo Project, Ministry of Culture, Egypt, 2006, pp. 374-403.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Gehan Nagy, Khalid Dewidar has executed and organized the workshop.

Mona Azouz, Marian Nessim, Dina Salem carried out the fieldwork and analysed the case study.

Yasmine Sabry was responsible for the data available on the case study.

Fayrouz Ashraf was responsible for the data collection of literature review, case study analysis and the workshop output.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

This paper is part of a funded project by the STDF (Science and Technology Development Fund) ID 41601. The project is a collaboration between three institutions: The British University in Egypt (BUE), Housing & Building National Research centre (HBRC), and the Zagazig University.