Atmospheric deposition: Effects on sculptures

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Abstract
Public concern over the deleterious effects of atmospheric deposition (AD) has grown rapidly due to its adverse effects (teratogenicity, toxicity, and carcinogenicity) to human, animals, and materials. The aim of this review is to describe the effect of the AD on sculptures, measures for its reduction, and case studies on maintenances of sculptures against the AD. To this end, a step-by-step review is outlined to discuss the harmful effect of AD contamination on many important sculptures. The review paper is also extended to describe preventive steps to reduce AD on sculptures to help reduce the risks associated with AD.

Keywords: Atmospheric deposition
Acid rain
Sculpture
Metal
Adverse effect
Maintenance

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Capsule Summary: This review was undertaken to provide the information on the effect of atmospheric deposition on sculpture. To this end, a step-by-step review outlined the effect of AD on sculptures and suggestion to reduce the AD effect.


INTRODUCTION
The sculpture is a branch of the visual arts and it is a plastic art. Sculptures are used to describe large works, which are known as monumental sculpture. The sculpture is associated with religion (ancient Greek art), culture, and public art. The sculptures are made of different classic materials, such as metal, pottery, wood, bronze, stone, bone, gold, silver, jade, and ivory. Other, less expensive materials are hardwoods (such as oak, box/boxwood, and lime/linden); terracotta and other ceramics, wax), and cast metals such as pewter and zinc (spelter). Sculptures are painted, waxed, oiled to preserve them (Steiger, 2015).

Materials used in sculpture

Metal
Most popular metals used for sculptures are bronze and related copper alloys. A bronze sculpture made of its alloys is ductile when compared to various ceramic or stone materials. Gold is a softer precious metal, and useful in
jewelry. It is with malleable and can be shaped (casting) in any form. Casting is a process by which a liquid material (bronze, copper, glass, aluminum, iron) is (usually) poured into a mold (desired shape), and then allowed to solidify. This process is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other methods (Rao et al., 2014).

**Stone**

The rough natural stone is used in making stone sculpture. This has been used by earliest societies. Part of the earliest form was the engraving of images on rock surfaces by incising, pecking, carving, and abrading. Stones are used in monuments and architectural sculptures, which are attached to buildings (Rao et al., 2014).

**Wood**

Wood is widely used in wood carving. It has disadvantages, of being vulnerable to decay, insect damage, and fire if compared to other materials in sculpture making. Outdoor wood sculpture does not last long in most parts of the world. Wood is commonly used in African, Chinese, Japanese, and Oceania cultures. Wood is light, suitable for masks, easier to work than stone, can be painted, and can be plastered to protect the sculpture from pollution (Rao et al., 2014; Steiger, 2015).

**Pottery**

The use of pottery is old in sculpture making. Sculptors build small preliminary works called maquettes of ephemeral materials such as plaster of Paris, wax, unfired clay, or plasticine. African cultures have produced pottery which combines a function as a vessel with a sculptural form, and small figurines have often been as popular as they are in modern Western culture (Rao et al., 2014).

**Glass**

Many working methods in sculpture making have made use of glass in recent development. It can be carved, with little or no difficulty. Hot casting can be done by ladling molten glass into molds that have been created by pressing shapes into the sand, carved graphite or detailed plaster/silica molds. Kiln casting glass involves heating chunks of glass in a kiln until they are liquid and flow into a waiting mold below it in the kiln. Glass can also be blown and/or hot sculpted with hand tools either as a solid mass or as part of a blown object (Rao et al., 2014).

**Air pollution**

Air pollution is a number of different ways pollution exists in the air. On a global scale, air pollution is discussed in relation to carbon dioxide (CO₂) and other greenhouse gas emissions (Howard-McGuire, 2013). Greenhouse gas emissions are issues throughout the universe. These issues have implications for public health. Particulate matter, sulphur dioxides (SOₓ), nitrogen oxides (NOₓ) and ozone (O₃) are some of the air pollutants (Nielson, 2013). The contributing factors of airborne pollutants in different cities of the world are the burning of fossil fuels, vehicular movements, high population increase, Coal-fired power plants, rapid economic growth, and others (Nielson, 2013; Abulude et al., 2018).

**Carbon monoxide (CO)**

The combustion of fossil fuels results in the emission of a variety of pollutants into the air. CO is one of the major ones present. The main sources of CO in the urban air are smoke and exhaust fumes of many devices, burning coal, gas or oil. The sculptures exclusively near the location of sources have detrimental effects like fading, breakage, corrosion, burns and the like (Nielson, 2013).

**Nitrogen dioxide (NO₂)**

This contributes a significant amount of the total loading of air pollution and acid rain. The biological sources of nitrate complicate the relation between atmospheric NOx levels and the occurrence of nitrates on exposed stone surfaces. The problem in finding calcium nitrate crystals on exposed stone surfaces is probably due to its very high solubility in water and its hygroscopic nature (Alghazawi, 2015). NO₂ drastically increases the corrosion rate of calcareous stones in SO₂-containing atmospheres at high (90%), but not at low (50%) relative humidity. Nitrate enrichment on different calcareous stone types is mainly from deposition of gaseous HNO and to a lesser extent, to dry deposition of NO. Microcracks in the stone structure caused by crystallization, and hydration, nitrates at ambient conditions may cause deterioration (Van, Grieken, 2010).

**Hydrocarbons (HCs)**

Hydrocarbons are present in coal, oil, and natural gas if these fuels are burnt carbon dioxide (CO₂) gas are when this gas is produced in excess it becomes air pollution (Usentaeva, 2014). An example is Volatile Organic Compounds (VOCs). The occupational exposures to tetra methyl lead, benzene vapours can cause health effects. Formaldehyde can cause irritation if inhaled. Hydrocarbon is contributory factors for eye and respiratory irritation which are caused by photochemical smog. Also, NOx gases react to form smog, acid rain and to the formation of fine particles (PM) and
ground-level ozone, all these have adverse effects on the materials used in the building or forming the sculptures (Van, Grieken, 2010).

**Aldehydes**

Aldehyde, ketone, and methane in engines have harmful effects on human health (irritation of eye, throat, nose, asthma, pulmonary function) and environment (Mathews, 2016). The pollutants add to global warming, which is a major concern worldwide (Kumar et al., 2011). It is useful in various ways: as a sterilizing agent and as a preservative in foods, cosmetics, pesticides, for biological specimens and for human remains. It is also added to adhesives, resins, and foams. It affects plants and wildlife in the environment. As a Volatile Organic Compound (VOC), aldehyde may be involved in the formation of ozone, which is harmful to crops and materials. According to International Agency for Research on Cancer formaldehyde, an aldehyde is a carcinogen (USEPA, 2014).

**Ozone**

Ozone is a very reactive substance. According to Rao et al. (2014), Ozone present in the lower layer of the atmosphere (Troposphere) is more dangerous than that present in the stratosphere. The Ozone present in the stratosphere prevents the passage of UV radiation onto the earth as it shows an adverse effect on sculptures (Rao et al., 2014).

Ozone is produced when the sunlight reacts with pollutants in the atmosphere (upper) and at the indoors by electric or light equipment (photocopy machines, printers, some air filtering equipment). When sulphur and nitrogen compounds combine with moisture and other contaminants in the air, sulfuric acid or nitric acid is produced. Then this acid becomes problematic thereby causing deterioration in a wide variety of items (sculpture inclusive). Objects in the vicinity react directly with ozone thereby causing deterioration on the said objects (Rao et al., 2014).

**Sulphur dioxide**

Sulphur dioxide (SO$_2$), and hydrogen sulphide (H$_2$S) are produced by burning fossil fuels, sulphur bearing coal, and

<table>
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<th>Table 1: Materials for making an outdoor sculpture</th>
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<td><strong>Object Materials</strong></td>
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<td>Metals</td>
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<td>Stone</td>
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<td>Paint</td>
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<td>Textile dyes and Pigments</td>
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<td>Ceramics</td>
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other organic materials. SO₂ is the most notorious pollutant responsible for metallic corrosion. Corrosion of sculptures made of hard metals (steel) starts at an annual mean concentration of 0.02 ppm. Sulphuric acid mist in the air causes deterioration of marble sculptures (Rao et al., 2014).

**Ethylene**

This is one the groups of substances known as the volatile organic compounds (VOCs). It may occur from chemical facilities using it, released in vehicle exhaust fumes, from waste incineration plants, in cigarette smoke (in traces) and naturally from green plants, fruits and other living organisms (SEPA, 2016). The problem may set in if the air is inhaled, resulting in a headache, drowsiness, dizziness, nausea, weakness, and unconsciousness. Studies have shown that ethylene is metabolized to ethylene oxide, which has more adverse effects on human health (SEPA, 2016). The International Agency for Research on Cancer has designated oxide of ethylene (ethylene oxide) as a carcinogen. In Canada, ethene in the air are reported to be from the combustion of fossil fuels to the use of ethene in various industrial processes and exhumed from cars older than 1992 (CEPA, 2016).

**Particulate matter (PM)**

Solids that are suspended in the air are referred to as Particulate pollutants. PM sources are either anthropogenic or non-anthropogenic, these could come from both outdoor and indoor sources. Pollution particles are mainly dirt, dust, mold, pollen, and skin cells, and a variety of other materials that are mixed with smaller amounts. Pollutants diameter is in microns (1/1,000,000 of a meter). Knowledge of particulate size is important when one is working on the size of air filters in a building (Rao et al., 2014).

Some particles like pollen, mold and skin cells can be attractive to pests. When this happens deterioration occurs. Particulates are particularly dangerous when they attract moisture and gaseous pollutants. When PM interacts with gaseous pollutants, deterioration can occur as a result of the followings:

- When sulphates and nitrates come in contact with moisture, they become acidic.
- When it acts as a catalyst for the chemical formation of acids from gases
- When it becomes an attractant for moisture and gaseous pollutants

**Causes of air pollution damage**

**Traffic**

The congestion of traffic on the roads increases vehicle emissions, which degrade ambient air quality. This vehicle emission has resulted in morbidity and mortality of drivers, commuters, and individuals habiting besides major roadways (Hsermes, 2012). The pollutant emitted by petrol, diesel, and alternative-fuel engines are CO, NOₓ, un-burnt HC's and PM. Vehicle pollutants cause immediate and long-term effects on the environment, for example, car exhausts emit a wide range of gases and solid matter, which cause global warming, acid rain, and which in turn harm the environment, human health, and materials (sculptures inclusive) (Green, 2018). Results from a research showed that health risks from traffic congestion are significant, and additional traffic can significantly increase risks, depending on the type of road and other factors (Zhang and Batterman, 2013).

**Industrial plants**

The presence of chemicals, particulates or biological compounds in the atmosphere can harm human and animal health and damage the environment. Factories and other industrial installations have caused such pollution since the dawn of the industrial age by burning fuels, carrying out chemical processes and releasing dust and other particulates. Air pollution can be controlled through the installation of filters and scrubbers to clean exhaust fumes from factory processes, and by taking steps to minimize the generation of pollution at the source (Zhang and Batterman, 2013).

**Natural disaster**

Hurricanes, tornadoes, wildfires, storms, drought, floods, earthquakes, and volcanoes are examples of a natural disaster. There are three main causes of natural disasters (movement of the Earth, the weather, and extreme condition). It is difficult to predict these natural disasters, they can occur suddenly. Tropical storms are caused by hurricanes, when there is too much water in any water source, a flood occurs, and earthquakes can happen when the Earth’s plates shift or jam above or underneath each other. These events cause loss to man, animals, and materials (sculptures are not spared) (Watson, 1997).

**Agricultural activities**

There are four main agricultural activities (soil management, enteric fermentation, manure management and fossil fuel consumption) according to the USEPA (2014). These are linked to the production of greenhouse gases. Agricultural activities like the use of insecticides, herbicides, and fungicides may end up causing air pollution. When fossil fuels are burnt, the gasses are released into the air which, in turn, causes air and water pollution. If the gases (carbon
monoxide, nitrogen oxides, sulfur oxides and hydrocarbons) are released into the air, they become carcinogen and, form acid rain when mixed with rain. The USEPA reported that agricultural activities accounted for about 12% of emission the US in 2012 (USEPA, 2014).

Burning of biomass

The burning of biomass (crop stubble, forest residues, and vegetation) is the combustion of organic matter in natural or man-made fires. Biomass burning is one of the sources of many PM and trace gases that increase the concentration of ozone at ground level. The smoke from the burning is composed of CO₂, H₂O vapour, CO, particles, HCs, NO₂ and many other compounds. The type of wood and vegetation being burnt, the temperature of the fire and the wind conditions dictate the type of smoke. Burning of biomass is rampant in Africa, Asia and elsewhere in the world (Chen et al., 2017). Efforts are being made throughout the world to reduce the burning of biomass.

Factors affecting pollution damage

Relative humidity (RH)

RH is a relationship between the volume of air and the amount of water vapor it holds at a given temperature. In RH,
water plays an important role in various chemical and physical forms of deterioration. There are many sources of excess water in the vicinities of sculptures. Examples are wet mopping, rain, flooding, leaking pipes, broken gutters, exterior humidity levels, nearby bodies of water, wet ground, moisture in walls, human respiration and perspiration, and evaporation.

The absorbance and giving off of water by organic materials and some inorganic materials depends on the RH of the surrounding air. Sculpture made of metals will corrode faster at higher relative humidity than other objects. There are the swelling and warping of wood and ivory, sculptures made of paper may cockle, or buckle; stretched canvas paintings may become too slack, and there could be mold growth. At higher RH, pests are more active. It is important to note that the temperature of the air determines how much moisture the air can hold. Warmer air can hold more water vapor. At low levels of RH, sculptures tend to shrink, discolour, stiffen, crack, disintegrates, and a flake off (Green, 2018).

**Temperature**

Temperature is the measure of the movement of molecules in an object. Molecules are the basic building blocks of all things. As the temperature increases, there is an increase in the speed of molecules in an object, they move faster and spread out; the object then expands. When it is another way round i.e, the temperature reduces, molecules slow down and come closer together; material, then contracts. Temperature and temperature variations can directly affect the preservation of sculptures in many ways. For example, at higher temperatures, chemical reactions increase, thereby causing deterioration by discoloration or disintegration of sculptures. If this deterioration is not detected, it can lead to a fire. Insects may eat more and breed faster, and mold will grow faster within certain temperature ranges. At high temperatures, sculptures can soften. Wax on sculptures may sag or collect dust more easily. At low temperatures, sculptures can cause desiccation which may eventually result in fractures of paints. Fluctuation in temperatures can cause sculptures to expand and contract rapidly. Temperature is a primary factor in determining RH levels. As temperature varies, RH also varies (Livingston, 2016; Abulude et al., 2017).

**Radiation**

Ultraviolet and visible light is radiation that disintegartes, fades, darkens, and/or yellows the outer layer of organic materials and some colored inorganic materials - unnecessary visible light that fades or darkens the outer layer of paints and wood (Livingston, 2016).

**Contaminants**

Another factor that affects air pollution is contaminants. These include gases (H₂S, NO₂, SO₂, and O₃; O), liquids (plasticizers that ooze from adhesives, grease from human hands), and solids (dust that can abrade surfaces, salt that corrodes metals). Contaminants disfigure sculptures, making them unpleasant to see, making them an eye saw within the vicinity of erection or placement (Abulude et al., 2017; Green, 2018).

**Light**

Light is a form of energy that stimulates our sense of vision. It is a factor of deterioration. The unit of measurement is the
nanometer (1 nanometer (nm) equals 1 thousand millionth of a meter). It can cause damage to the sculpture. It causes fading, darkening, yellowing, embrittlement, stiffening, and a host of other chemical and physical changes. Sculptures made of these materials book covers, inks, feathers, furs, leather and skins, paper, photographs, textiles, watercolors, and wooden are sensitive to light. All types of lights emit varying degrees of UV radiation. This radiation (which has the most energy) is the most damaging to sculptures (Livingston, 2016).

**Deterioration to sculpture caused by air pollution**

According to Smithsonian American Art Museum (2015), outdoor sculpture is traditionally made of stone and metals (Table 1). The most vulnerable materials in sculpture making are marble and limestone to acid rain (Steiger, 2015). Other types of materials like granite and sand stone are resistant to acid attack. Cast iron, steel, zinc and lead, and bronze have also been used in sculpture. In a review by Tidblad (2015), bronze (Cu-Zn-Sn-Pb) has been preferred for sculpture since ancient times because of its resistance to corrosion and favorable casting properties. Pure copper is too soft for practical applications (Livingston, 2016). Other elements have usually been added to harden it and to change its colour. In antiquity, tin was the major alloying element, despite its high cost. Small amounts of lead improve the flowability of the molten bronze and enhance its ability to reproduce fine details.

In affirmation to the deleterious effects, air pollution has on sculptures, the pictures in Fig 1 show why it is good to prevent or reduce the effects of air pollution.

**Cases of sculpture damages and maintenances**

The cases in this paper are taken from the project overview of Conservation Solutions Inc, Canada (CSI). They depict the steps, maintenance and major restorations needed for sculptures.

**New York**

**Tennessee marble lion sculptures**

The maintenance work on the sculpture was undertaken by CSI. The project was to remove iron stains left behind on the stone by holiday wreaths. The works were limited to a light general cleaning and stain removal on the sculptures (CSI, 2017a). Other, includes removal of atmospheric soiling, biological growth, gypsum crusts, and iron stains. Cracks and losses in were filled with injection grout and color matched patching mortar (Fig. 2).

**Columbia University’s Morningside heights campus**
The bronze sculpture was worked upon to improve the dark coloration of the statue, obscuring its natural patina (Fig. 3). This maintenance work was performed by removing the existing wax coating. The bronze sculpture was spot-patinated to reduce the contrast between the areas of light green and black corrosion. The maintenance work was performed to increase the longevity of the sculptural treatment and to help reduce future deterioration (CSI, 2017b).

**Metropolitan museum of art's American Wing courtyard**

The reinstallation was performed on the pulpit salvaged from All Angel’s Church (Fig. 4). The reinstallation was based on the careful removal of each surrounding mortar joints by hand sawing. Care was taken to ensure no other damage. The element was carefully replaced in its original position and orientation. At the end of the exercise, newly carved limestone replacement blocks were integrated into the installation (CSI, 2017c).

**Florida**

**Fernando Botero's three Bronze sculptures**

The three bronze sculptures are located at the Museum of Fine Arts in Saint Petersburg, Florida (Fig 5). The sculptures lost some of its protective wax coatings and also suffered damages to the foundry applied patinas due to the exposure to sun and wear. The salvage to the bronze was done by cleaning using anionic detergents and water, waxed, dried, heated with propane torches, re-waxed, and protected with corrosion inhibitors (CSI, 2017d).

**Flagler memorial monument**

This monument is sited on a man-made island in Biscayne Bay, between Miami Beach and Miami (Fig 6). The monument was damaged by vandalism and corrosion of the internal reinforcing. Surface erosion deteriorated the legibility of the forms. The solutions to these problems were provided by CSI. The entire monument was cleaned, loose and flaking paint and previous repair parges were removed, damaged concrete blast-cleaned, treated with a corrosion inhibitor and a protective coating, and rebuilt using restoration mortars. Cracks were injected with a compatible grout, and the entire structure was then coated with a potassium silicate paint matching the historic color (CSI, 2017e).

**Lead sculptures conservation**

The outdoor sculpture collection of Vizcaya Museum and Gardens in Miami, Florida (Fig 7) was preserved due to its vulnerability to damage due to air pollution. The lead sculptures became distorted, sagged and deformed under its weight. The CSI (CSI, 2017f), corrected and repaired the sculptures. The following steps were adopted: the surface accumulations, concrete, fiberglass, and synthetic resins were
removed. Internal armatures were used to support the weight of each statue, cracks and previous losses were filled, and a patina was chemically developed on the surface, and they were re-installed in their original locations.

**Steps to minimize the effects of air pollution on sculpture**

1. Washing with detergents (anionic) and water
2. Waxing and Rewaxing
3. Application of corrosion inhibitors
4. Cracks and losses should be filled with injection grout and color matched patching mortar.
5. Painting (suitable paints - potassium silicate).
6. Heating, Ventilation, and Air Conditioning
7. Understanding the Effects of Different Temperature and Humidity Levels
8. Adequate use of monitoring equipment (Chicora Foundation, 1994)

**CONCLUSIONS**

Sculptures are used to describe large works, which are known as monumental sculpture. They are made of different materials like wood, stone, metal, and others. From this review paper, it could be noted that sculptures are adversely affected by air pollutants (PM, gases, and metals). The metals can corrode, the stone can deteriorate, dyes can fade quickly, polymers can breakdown rapidly, and paints can weather faster. In the long run, the sculpture may be defaced or damaged which eventually results in a loss. Steps to minimize the effect could be air conditioning, washing and rewaxing, painting, and the application of corrosion inhibitors just to mention a few. It is recommended that constant monitoring of atmospheric deposition should be ensured so the sculptures can be protected from damage or eventual loss.

**REFERENCES**


Kumar, S., Nayek, M., Kumar, A, Tandon, A., Mondal, P., Bhangale, U.D., Tyagi, D. 2011. Aldehyde, Ketone and...


Mathews, P. 2016. What are the effects of aldehydes and ketones in the atmospheric air? Quora


Scottish Environmental Protection Agency (SEPA), 2016. Formaldehyde. Scottish Pollutant Release Inventory.


