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Sustainable Development of Cultural Heritage Via Anti Weathering Nanoparticles Material

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Abstract: Egypt's modern architectural heritage is eroding fast. Many buildings have been erased or simply neglected. The growing interest in the conservation of historic buildings encourages the development of controlling heritage decay using future practical repair interventions as water–repellent materials and methodologies to consolidate and/or protect stones. This paper tackles the process of adaptive reuse as an important stage in conservation following restoration and links it to the sustainability of the built environment. This research suggests a way to protect two heritage buildings in Cairo: One located on a main highway road leading to the International Airport of Cairo, exposed to traffic pollution, and the other located in a small street surrounded by many polluting car repair workshop in downtown Cairo, using titanium dioxide nanoparticles – polyalkylsiloxane to treat the building surfaces. Two methods of application were used to show the effect of different nanoparticles concentrations. The results show that maximum water repellency and hydrophobicity are obtained at 2 % titanium dioxide nanoparticles concentration via spraying on painting surfaces.

Key words: Architectural heritage, Sustainable development, Water repellent, nanoparticles, Palaces in Cairo.

INTRODUCTION

Historic buildings are nowadays extremely important as they so often provide our cities and towns with their identities. Culturally, historical buildings are a record of the architectural evolution of the area. Socially, they are a source of national pride. Saving historical buildings provide economic benefits to the community, by capitalizing on historic and cultural resources. Sustainable development is defined as "development that meets present needs without compromising the ability of future generations to meet their own needs" [Colgan and Donlong, 2010].

This paper will argue that sustainability can serve as a tool to achieving heritage conservation, which in turn can serve as a tool for achieving sustainability and clarify the fundamental role of heritage conservation in sustainable development [Hutchings and Cassar, 2006; Giorgi *et al.*, 2010; Mubin and Kamaruddin, 2012; FuWei *et al.*, 2012].

Egypt is a country with a rich history and cultural heritage; it is also a country that has sought to develop law and policy to protect a broad range of its heritage. Many priceless architectural treasures built by internationally famous architects are left to decay. So, it's mandatory to implement ratification of key international heritage treaties, as well as national and local initiatives. However, contrary to exceptions, polymers used for the protection of wall paintings have induced further degradation of the works of art and their chemical modification; hence, the need to develop new methods.

Recently, particular attention was devoted to composites of inorganic oxides nanoparticles and hybrid siloxane or silicone polymers to obtain superhydrophobic surface, and this is attributed to the textured surfaces of the siloxane – particle composite films [Hwang *et al.*, 2008; Rioboo *et al.*, 2008; Manoudis *et al.*, 2009 a,b]. The most common nanoparticles are silica (SiO_2), alumina (Al_2O_3), tin oxide (SnO_2) and titanium oxide (TiO_2) [Manoudis *et al.*, 2008; Peifu *et al.*, 2011]. There are numerous researchers who fabricated surfaces which imitate the surface structures of the superhydrophobic biosurfaces, by using numerous techniques and methods, for example, plasma treatment [Shang *et al.*, 2005; Hwang *et al.*, 2008; Manoudis *et al.*, 2008; 2009 a,b], photolithography (casting polymers under controlled conditions or on appropriately designed / selected templates) [Lafuma and Qu´er´e, 2003; Lai *et al.*, 2008], sol–gel, electrospinning, deposition of nanoparticles on smooth or microroughened substrates, deposition of nanoparticle – polymer composites on smooth surfaces [Qian and Shen, 2005; Taurino *et al.*, 2008; Dirè *et al.*, 2011], growth of aligned nanotube or polyacrylonitrile nanofibers, laser fabrication and controlled grain growth [Kulinich and Farzaneh, 2004; Cai *et al.*, 2005; Boduroglu *et al.*, 2007; Hwang *et al.*, 2008; Lai *et al.*, 2008; Yang and Deng, 2008; De Ferri *et al.*, 2011].

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Water repellent coatings can be important in many applications including for example the prevention of icing in cold weather and the promotion of self–cleaning processes induced by rainwater on outdoor surfaces (automobiles, buildings, antennas, traffic lights, etc.) [Kulinich and Farzaneh, 2004; Bhushan and Jung, 2007; Boduroglu *et al.*, 2007; Yang and Deng, 2008]. Another promising application of the superhydrophobic coatings is their use as surface protective barriers for the preservation and conservation of monuments. The most important degradation factor of outdoor immovable cultural heritage is acid rain water which is attributed to different air pollution sources and can cause stone deterioration through cycles of freezing and thawing inside the pores of the stone or by intra porous crystallization of the salts transferred by water. For this reason, the application of hydrophobic coatings has been suggested as a potential strategy for the surface protection of outdoor cultural heritage assets [Soeno *et al.*, 2004; Manoudis *et al.*, 2009 a,b]. Recently were described two very simple methods that can be used to impart superhydrophobicity to a large variety of different surfaces including marble, a material that has been very often used in cultural heritage objects [Manoudis *et al.*, 2008; 2009 a,b]. The method is summarized as follows: nanoparticles are dispersed in a (siloxane) polymer solution. The mixture is then sprayed on the substrate and the resulting composite polymer–nanoparticle film exhibits superhydrophobic properties.

In the present study the aforementioned method is employed to treat cement stone. The commercially available polyalkylsiloxanes "Rhodorsil 224" is used to treat the surfaces of the stones. The main goals of the research are to reflect the importance of heritage conservation in the enhancement of both the sustainability of a city and the quality of life in the community. As these buildings have tended to be in prominent locations, our target should be to make sure that these important buildings not only remain in existence but continue as civic institutions and public amenities. This approach helps better understanding and sustainability of future restoration projects in Egypt. To achieve these goals, the present study demonstrates that the hydrophobic character of the siloxanes, can be easily enhanced by mixing them with Titanium dioxide nanoparticles at different concentrations. The siloxane – nanoparticle composites are applied using two different techniques (spraying or painting) on the cement stones, and the treated surfaces exhibit super hydrophobic properties. The following chart (Fig.1) shows the three main phases of heritage conservation that should be followed as recommended by the researchers. Highlighted areas indicate the tackled parts in this study.

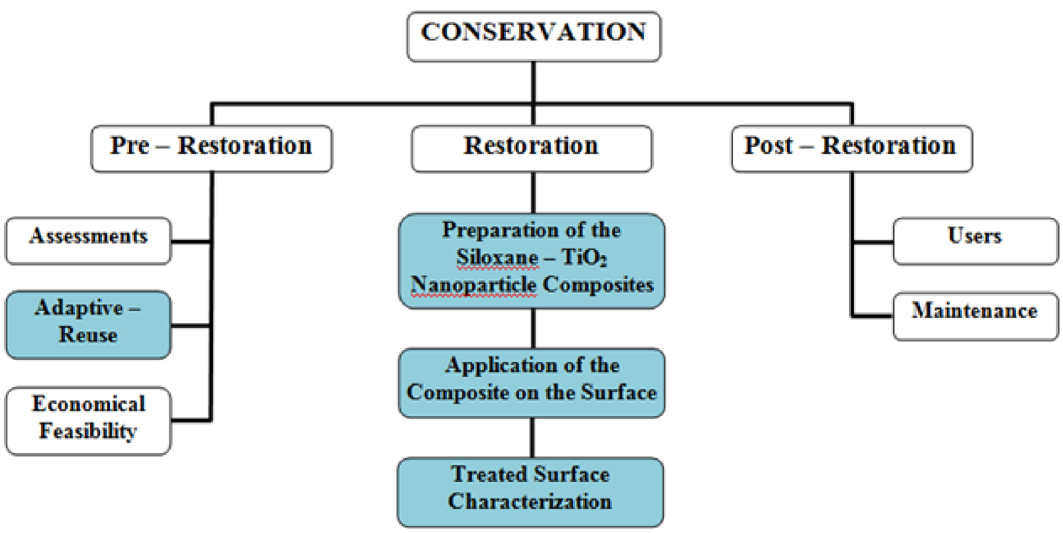


Fig. 1: The chart of the research.

Importance of Adaptive Re–Use:

1. Defining Adaptive Reuse of Heritage Built Environment:

An "Adaptive re–use" is not only an important concept in heritage conservation policies, but is also given due regarding in the heritage conservation work of cities all over the world. Adaptive reuse is a process that changes a disused or ineffective item into a new item that can be used for a different purpose for future generations. This forward–looking, long–term heritage conservation strategy has innumerable benefits to our environmental, economic, and social well–being. Keeping and reusing historic buildings has long–term benefits for the communities that value them. Because of this, the research will explore some of the environmental, social and economic benefits of the adaptive reuse of historic buildings [Wangkeo, 2003].

2. Environmental Benefits of the Adaptive Reuse of Historic Buildings:

By reusing buildings, their embodied energy is retained, making the project much more environmentally sustainable than entirely new construction. New buildings have much higher embodied energy costs than buildings that are adaptively reused [Lowenthal, 1975].

3. Social Benefits of the Adaptive Reuse of Historic Buildings:

When adaptive reuse involves historic buildings, benefits are more significant, as these buildings offer so much to identity and amenity of the communities they belong to [Lowenthal, 1975].

4. Economic Benefits of the Adaptive Reuse of Heritage Buildings:

There are several financial savings and returns to be made from adaptive reuse of historic buildings. Buildings that should be saved and restored are not only those which are architecturally and structurally highly valuable buildings, but also those with great historical, cultural and symbolic value to the local community. These international examples reflect the importance of heritage conservation in the enhancement of both the sustainability of a city and the quality of life in the community [Alsayyad, 2001].

MATERIALS AND METHODS

1. Case Studies of Heritage Buildings:

Air pollution has increased dramatically the last decades threatening more the sustainability of Heritage buildings. Sulfur and nitrogen oxides as well as hydrocarbons are daily emitted into the atmosphere due mainly to industry, air conditioning and transportation. As far as air pollutants are concerned, an important process which contributes to the damage of artworks, decorative walls and irreplaceable sculpturing, is pollutant deposition and adsorption. Examples of those sites are the Palace of Said Halim in Down Town Cairo, and Palace of Baron Empain Heliopolis, Cairo. Both chosen heritage buildings were built during the 19^{th} century and witnessed many historic circumstances. They have distinct unparalleled architectural character and styles [Owen, 1972]. In addition, many of these structures are considered as National landmarks, situated in prominent positions but exposed to pollution. The following summaries the peculiarities of those sites:

1.1. Palace of Said Halim:

A) History:

This Cairo residence was built in 1896. By 1940, the palace became Al–Nassereya boys' school, a leading institution for the sons of Egyptians elite as shown in Fig (2–a). The palace became the unlucky ward of the ministry of education. Thereafter, the deterioration came in steady increments fueled by ignorance and greed. A dispensary here, an office for the ruling party there, plus the indiscriminate building of brick walls on the balustrades and the pilfering of the priceless pink marble and other rare historical rarities [Tamraz, 1998]. In 2004, the school was closed and the palace has been out of use since then. The palace only closed its doors in 2004 as it was finally included in the register of the Institute Francais d' Archaeologie Orientale, which seeks document for all monuments. The palace has been out of use since. Today, the palace is an abandoned building surrounded by shrouded overgrown trees and shrubbery, drowning in its own dust and rubble, its doors and windows falling from their hinges.

B) Location:

The palace is located in Champolion Street, Bab al Luq, Abd El–Moniem Riad Square, this street being named after the famous French Champollion.

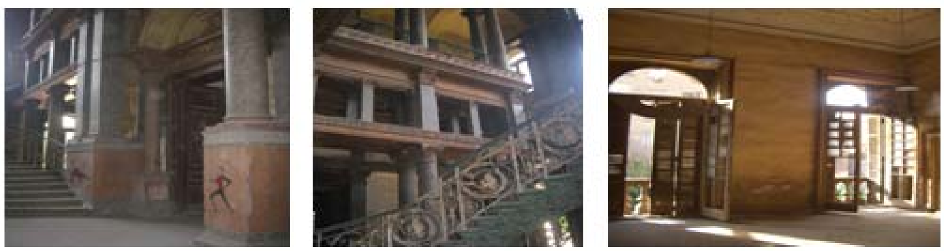
C) Architecture:

Halim commissioned a well known Italian Architect to design the palace among other regal downtown building the palace of Princess Neamat Kamalleddine and headquarters of bank Misr, in line with Extravagant tastes of the house of Mohamed Ali. Halim was obsessed with Rome, So as expressed by El–Aref [2005]. Fig (2–b) and Fig (2–c) manifest the architecture of the palace, which was built from materials directly imported from Italy.

The 19^{th} century classical and red marble stones give the whole structure a soft pink glow. Today, there is still evidence of grandeur: classical arches, Braque overlays, the prince's initial (SH) alternating with angels and ottoman logo on the surface of the pillars. The palace is massive with gorgeous wraparound balconies.

a) Al–Nassereya boys· School

b) Outdoor Photos



c) Indoor Photos

Fig. 2: Photos of Said Halim Palace.

D) Major Threats to the Building:

The building is surrounded by many car repairing workshops and is highly exposed to air pollutants and garbage. As expressed by El–Aref [2005], this palace is extremely threatened by many elements. Some workshops are adjacent to the site contradicting with its grandeur and richness.

1.2. Palace of Baron Empain:

A) History:

At the end of the 19th century, after several years from the opening of the Suez Canal, a millionaire and outstanding engineer Belgian, Edouard Empain took the fateful decision to remain in Egypt until his death. He looked for a permanent residence and chose a place in a desert near Cairo and decided to build a palace (1906 to 1911). The title "Baron" was given by the king of France to Empain for his efforts in the establishment of the Paris Metro. Fig (3) shows both of outdoor and indoor photos of this palace [Yûsuf, 1982].

B) Location:

This magnificent palace was perched quietly on a hill high up in the desert of Heliopolis. The Baron chose this place as adjacent to Cairo and close to Suez in order to enjoy the atmosphere where serenity and purity of the air in this piece of desert east of Cairo. This palace was built at the highest hill at last limits of Cairo in the desert surrounding Abbassia, occupying an area of 30,000 m^2 [Johnston, 2006].

C) Architecture:

The Baron has made a decision that resides exclusively unparallel in the whole world, as he asked French architect Alexander Marcel to built him a Hindu palace, with a number of Italian and Belgian engineers. The palace was designed in a way that makes all this rooms exposed to the sun. The palace Tower is to move according to the direction of the sun, installed on a base run by two motors. Empain lived ancient myths, so the design was dominated by Indian–style. It was a masterpiece, mixing different architectural styles: Indian, Chinese, Arab and Roman. At the entrance, there are elephants at the top of the gateway and there are snakes, Greek statues with Chinese dragons and legendary monsters with Buddha, Shiva and Krishna all in the wonderful harmony in front of the building as shown in Fig (3–a). Inside the palace, white marble statues were bought from Indian. Ivory statues are spread inside and outside; moreover, the windows are up and down with statues. Marble was brought from Italy and crystal from Czechoslovakia. Rooms have balconies covered with colorful mosaic floors [Johnston, 2006].

D) Major Threats to the Building:

This magnificent palace is located on a main high way road leading to the International Airport of Cairo, exposed to traffic pollution.

2. Materials:

In this research polyalkylsiloxane was used as hydrophobic long–chained alkylsilanes and titanium dioxide produced by sigma Aldrich and Rhodorsil 224" was used to treat the surfaces of the stones.

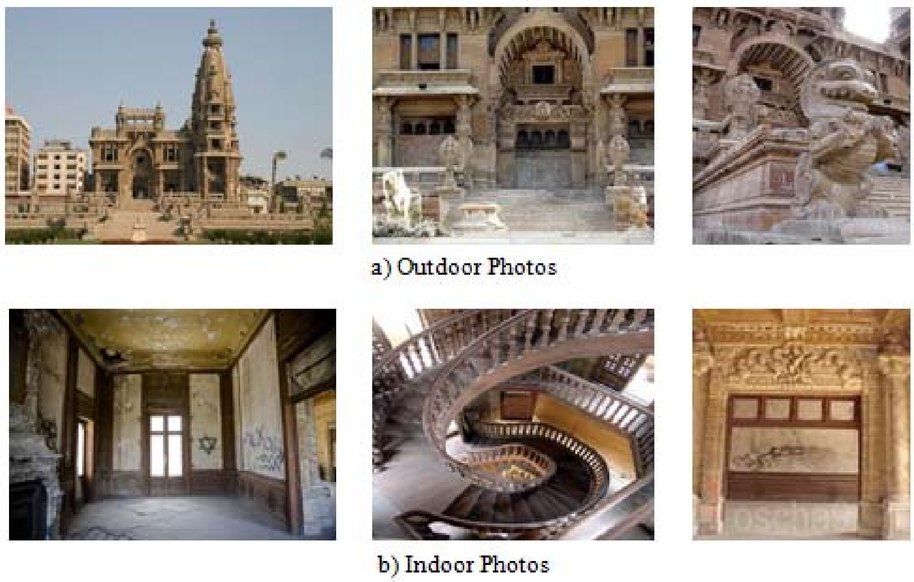


Fig. 3: Photos of Baron Palace.

3. Methods:

In this study concrete cubes of around (2.5 x 2.5 x 2.5) cm^3 were used. Specimens were washed with deionized water and acetone then dried [Manoudis *et al.*, 2009 a,b]. These cubes were coated with an engobe layer then painted to represent the wall of the cultural building. The chemical compositions of the cubes are shown in Table (1).

Hydrophilic white – colored nanoparticles with 5 nm mean diameter were mixed with 7 % w/v polyalkysiloxane solution in white spirit. Different percent of nanoparticles (0, 0.5, 1, 1.5, 2, and 2.5) % w/v were used for mixing with the above polymeric material. The mixtures were stirred vigorously for twenty min in order to obtain a homogeneous dispersion. Table (2) shows the additives to silica treatments for the improvement of physical / chemical properties of the surface.

Two different mechanisms were used for the siloxane–nanoparticle composites applications: 1) Sprayed on the painted surface of the blocks, 2) Painting, where this composite was mixed with the paint then coated the surface.

Table 1: Concrete cubes composition as European Standard [EN 206–1/2000].

Composition	By Volume of Concrete
Portland Cement	(10 – 15) %
Sand and Gravel	(60 – 75) %
Water	(15 – 20) %
Air Content	(5 – 8) %

Table 2: Additives to silica treatments for the improvement of surface physical / chemical properties.

Surface Property	Additive
Hydrophobic	Hydrophobic Long – chained alkylsilanes Polisiloxanes
UV – protective	Organic UV absorbers Inorganic pigments like TiO_2, ZnO
Photocatalitic	TiO_2

4. Hybrid System of Inorganic – Organic Nanoparticle Characterization:

1- The surface morphology was examined by SEM, and the siloxane matrix was estimated by EDX using micro–Raman spectroscopy with zoom magnification power up to 300000.

2- The efficiency of the treatments has been evaluated through static contact angle measurements and capillary water absorption. This test was carried out to determine sorptivity coefficient of concrete specimens which were preconditioned in an oven at 105 °C for 24 hrs and then cooled in a desiccators to achieve constant moisture [Bozkurt and Yazicioglu, 2010]. Four sides of the concrete specimens were sealed by paraffin to avoid evaporation effect and two opposite faces left unsealed. The initial weight of the specimens was recorded before locating it in water where one face of the specimen was in contact with water. The water absorption at predefined intervals was measured to an accuracy of 0.01 g. The sorptivity coefficient was calculated by the following expression:

$$S = (Q/A) / \sqrt{t} \qquad (1)$$

Where S is the sorptivity (cm/s$^{1/2}$), Q is the volume of water absorbed (cm^3), A is the surface area in contact with water (cm^2), and t is the time (s) [Bozkurt and Yazicioglu, 2010].

3- Exposure to artificial weathering was performed in an apparatus including fluorescent UV lamp (UVB–313) and condensation according to international standard [ISO 11507 / 2007]. The effects of accelerated weathering were evaluated separately by comparative testing of chosen parameters.

RESULTS AND DISCUSSIONS

1. Surface Morphology:

Fig (4) shows SEM images of the sprayed surfaces with different concentrations of titanium dioxide, and Fig (5) shows SEM image of nanoparticles deposition at 2 % concentration using painting technique, all in a 1000x magnification. From these photos, it is obvious that, when pure siloxane is deposited on the surface, a continuous film is formed which follows the roughness of the underlying substrate (Fig 4–a). When the surface is treated by spraying with a siloxane – TiO_2 dispersion concentrations of (0.5, 1, 1.5, 2, and 2.5), the surface roughness increases with increasing concentration of nanoparticles until 2.5 % w/v, protruded particle aggregates are formed on the surface according to Fig (4–f). Aggregates are separated by small, relatively smooth areas, which resemble the film produced by the deposition of pure siloxane with no particles.

In general, it can be deduced that maximum concentration of TiO_2 nanoparticles was 2 % via spraying on the painted surfaces. These results were confirmed by capillary water absorption, water repelling, and static contact angle measurements.

2. Formation of Hybrid System of Inorganic – Organic Nanoparticle:

Surface modification with inorganic or hybrid inorganic–organic systems was based on silica sol–gel materials (starting from alkoxysilanes), incorporating the metals or anchoring them through coordinative linkages. In this research we attempt to incorporate titanium dioxide nanoparticles in alkylsilane systems using the sol–gel method in which SiO_2 particles prevented the aggregation and further growth of titanium particles.

Fig (6) shows the effect of TiO_2 nanoparticles at low concentration (0.5 %) and high concentration (2 %) using the two previous application methods. The results indicate that the weight percent of TiO_2 is increased in the surface layer with increasing its concentrations from 0.5 to 2 % using the spraying method, while no change in percent weight of TiO_2 occurs on using the painting method at the same concentration (2 %) as shown in Fig (6–c).

3. Capillary Water Absorption:

Fig (7) shows the sorptivity values of treated surfaces by the two methods of application, with different concentrations of titanium dioxide. From this figure, capillary water absorption increases using painting technique more than spraying technique, and the highest value of sorptivity coefficient was obtained at 1 % TiO_2 concentration using painting method. On the other hand, the lowest value of sorptivity coefficient was obtained at 2 % TiO_2 concentration using spraying method. This is attributed to the fact that at 2 % titanium dioxide concentration and spray method, the pores between aggregate and interface are filled with titanium dioxide, and hence the capillary pore is reduced. The beneficial role of mineral addition causes an increase in the strength and reduction in the capillary sorption of surface [Bozkurt and Yazicioglu, 2010].

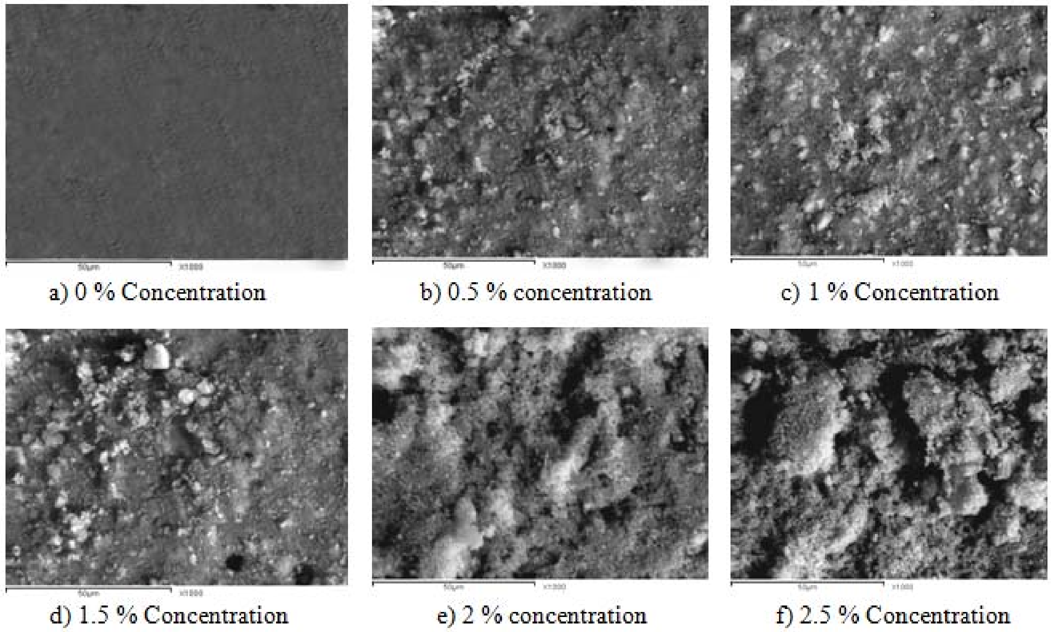


Fig. 4: SEM images of the sprayed surfaces with different concentrations of titanium dioxide nanoparticles – 1000x magnification.

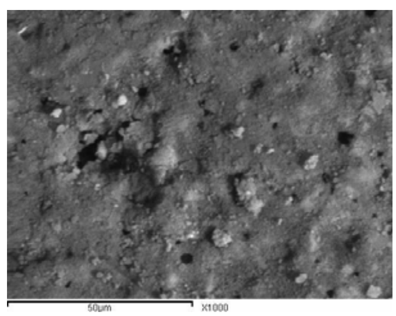


Fig. 5: SEM image of TiO_2 nanoparticles deposition at 2 % concentration using painting technique – 1000x magnification.

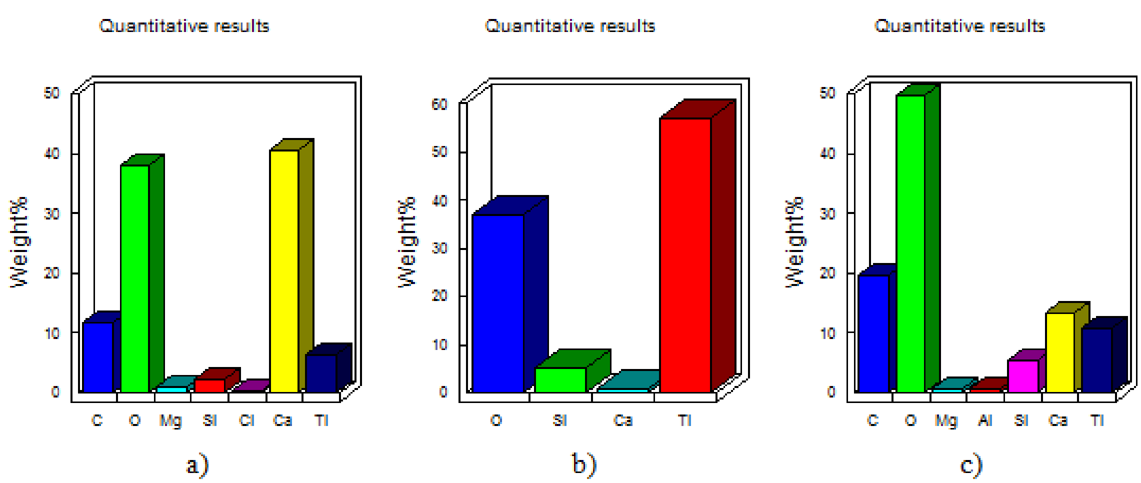


Fig. 6: EDX show effect of Titanium dioxide at low and high concentration; a, b) at 0.5 & 2 % concentration using spraying method, c) at 2 % using painting method.

On the other hand, application of titanium oxide nanoparticles on the surface enhanced the static contact angle and hydrophobicity. Fig (8) shows the photos of static contact pattern of sprayed surfaces with different TiO_2 nanoparticle concentrations from 0 % to 2.5 %, respectively, and Fig (9) shows schematically the static contact angle of sprayed surface with 2 % TiO_2 nanoparticle concentration. Also, Fig (10) shows the hydrophobicity values of treated surfaces by two methods of application, with different concentrations of titanium dioxide.

The results indicate that the static contact angle increase with increasing the TiO_2 nanoparticle concentrations from 0 % to 2 %, at which gives the maximum contact angle ($\theta > 165°$) (Fig. 9) and super hydrophobicity (Fig. 10). Incorporation of TiO_2 nanoparticles into the basic coating solution was performed to introduce roughness of the coating and, consequently, to increase the water contact angle. After that no significant improvement, was observed for the roughened film containing nanoparticles when the concentration was higher than 2 % [Hwang *et al.*, 2008; Förch, 2009].

Finally, it can be concluded that capillary water absorption, static contact angle, and hydrophobicity of the surface are enhanced by increasing titanium dioxide concentration up to 2 % using spraying method.

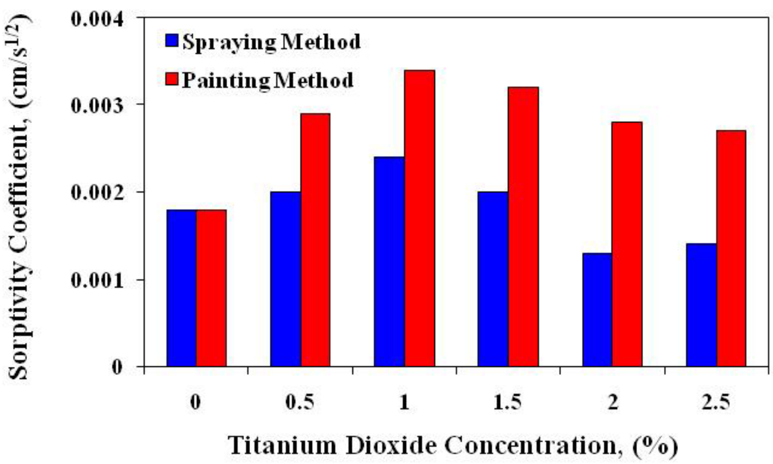


Fig. 7: Sorptivity values of treated surfaces at different concentrations of titanium dioxide.

Fig. 8: Photo of static contact pattern of sprayed surfaces with different TiO_2 nanoparticle concentrations from 0 % to 2.5 %, respectively.

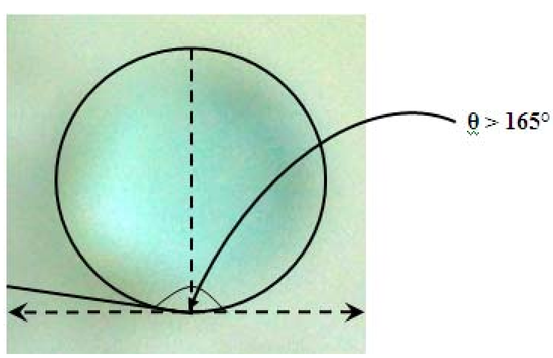


Fig. 9: The static contact angle of sprayed surface with 2 % TiO_2 nanoparticle concentration.

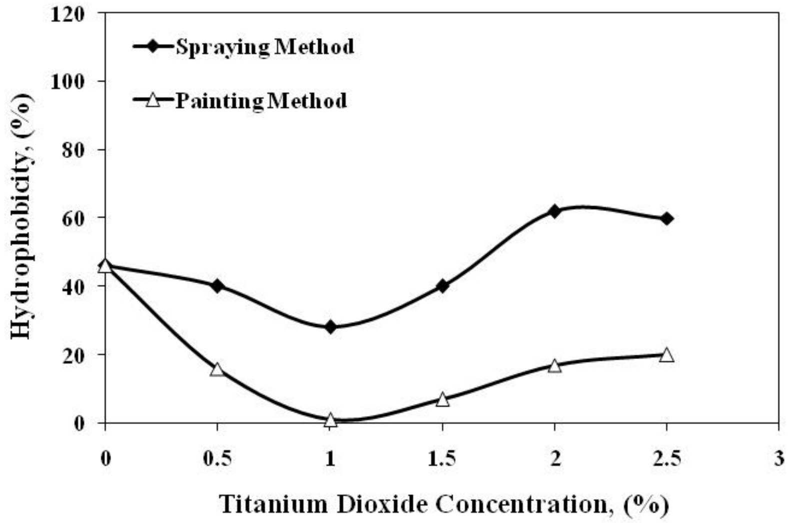


Fig. 10: Hydrophobicity values of treated surfaces at different concentrations of titanium dioxide.

4. Exposure to Artificial Weathering:

After exposure the recommended sample (2 % concentration by spraying method) to artificial weathering for 200 hours, there were no blisters, wrinkles, cracks, and fading of colour, with no loss of gloss (luster) [ES 793 / 2008].

Conclusions:

This study focused on the achievement of sustainability development of the Egyptian heritage buildings as a tool of conservation. The palaces of Said Halim and Baron are examples of two different age, locations and archeology art in Cairo. Due to the importance of these buildings, hybrid system of polyalkylsiloxane – titanium dioxide nanoparticles was applied to achieve the conservation of these buildings. Gel layers containing from 0 to 2.5 % titania nanoparticles were applied either by spraying or by painting. The addition of nanoparticles leads to the formation of superhydrophobic surface with highly developed nanostructure, and improves both capillary water absorption and static contact angle. A maximum hydrophobicity was achieved at 2 % titanium dioxide concentration applied by spraying on the surface.

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