Nanotechnology use to preserve the durability of archaeological brick buildings in Al-Najaf city

E A ALhilo¹, S A Kuba², A F Dirweesh³

¹Department of Environmental Planning, Faculty of Physical Planning, Kufa University, Najaf, Iraq
²Department of Urban Planning, Faculty of Physical Planning, Kufa University, Najaf, Iraq
³Department of Architecture, Technology University, Baghdad, Iraq
Email: entisara.alhillo@uokufa.edu.iq

Abstract. Archaeological buildings constitute the urban core of historical cities, supporting both private identity and urban life in society. Old Najaf city may be the most important city in Iraq due to its religious and spiritual value in the Islamic world; its archaeologic buildings thus represent the features of both collective memory and the private reality of cultural heritage. This research aims to achieve examine the use of nanomaterials in terms of contributing to the preservation of archaeological buildings built with bricks in Najaf City in particular, and Iraq in general, helping determine how to use these to prolong the life of these buildings based on the assumption that certain nanomaterials can prevent harmful environmental factors from affecting such buildings or causing further damage. This would allow a high level of environmental efficiency and help to perpetuate these historic buildings, as such treatments do not cause any changes in the original physical or chemical properties of heritage buildings. The study results suggest that Nano-treated bricks can effectively be used as a new building material for additive parts used to support archaeological buildings, thus offering access to buildings with high environmental efficiency.

Keywords: Nanotechnology, Durability, Archaeological buildings, Al-Najaf city.

1. Introduction

Conservation processes are related to the renewal and prevention of erosion in buildings and facades to extend the life of selected buildings; this includes interventions in various different circumstances and within specific environmental conditions in each city and for various building materials used in different areas. Nanotechnology has begun to contribute to this field, both in terms of preserving heritage buildings and restoring damaged parts, based on creating new building materials that reduce energy consumption, eliminate environmental pollution, and interact positively with environmental conditions. This research was thus focused on the importance of applying nanomaterials in terms of preserving archaeological buildings; as the most common building material used in the selected study area is brick, the focus is thus on the addition of nanomaterials to bricks, which has a major impact on reducing harmful environmental influences and sustaining the building material into the future. The data for the paper was collected by means of a literature survey from various secondary sources such
as books, journals, articles, and the sundry studies conducted regarding nanomaterials in this field. Key works in this area include
- Ion et al. (2017). These researchers showed that the smaller size, higher penetrability, greater viscosity, and improved thermal and magnetic properties of nanomaterials as compared to conventional materials increased their efficiency of use in the preservation and restoration of stone and paper crafts [1].
- Hemeda (2018). This study of the restoration of Al-Mahalla Mosque in Egypt offered an assessment of the current situation and a suitable restoration strategy based on an analytical study of major building materials, including an experimental study of samples of historical fired bricks using conventional materials that were then treated with nanomaterials. The study also proved the increased efficiency of materials treated with nanomaterials as compared to traditional materials on their own [2].
- Aljenbaz (2020). The paper clarified the application of nanomaterials in building production and examined these materials from architectural and sustainability perspectives. The study concluded by contributing to the literature bank of nanomaterials research [3].

After this literature review, a data bank was formed focusing on nanomaterial applications used to preserve archaeological buildings. The resulting paper is structured as follows: section one discusses the cognitive framework for the study, defining the concepts of permanence, nanomaterials, and archaeological buildings, and extracting indicators related to each of these to help determine the relationships between the three items. Section two includes an analysis of the types of nanomaterials used and how these affect the permanence of the resulting brick materials used in the support archaeological buildings in Iraq, helping determine how best to deal with these materials. Section three thus offers initial results, conclusions, and future recommendations.

2. Durability
Durability in architecture refers to the ability of the building to stay intact for a longer period that may exceed the time period originally specified for its functions both environmentally, and urbanely. Many architects have studied methods of preserving the permanence of urban structures, including Vitruvius and Palladio.

In “Ten books in architecture”, Vitruvius explained the importance of permanence in the three necessary factors of buildings, which are durability, convenience and beauty, while Palladio explained how materials are selected, processed and transformed from a raw natural state into building materials with more durable properties to allow them to work optimally [4].

1.1. The main pillars determining the permanence of archaeological buildings [5]
1- Environmental effects: these are the biggest influence on the durability of all building materials.
2- Human effects: permanence depends on the actions of human beings at all stages, however; this includes the selection, design, manufacture, and detailing of the materials used within a building and its ongoing use and upkeep.
3- Time effects: these determine the service life of the buildings.

Ruskin noted that it is only after four or five centuries have passed since building completion that the real value of truth of that building is available, as a building’s greatness lies not in its building materials, even in the use of precious metals, but rather in its age and in the ways its walls show the passage of the years, giving it its true colour. The true value of architecture is that it distinguishes heritage and archaeological buildings from other buildings, giving them identity and increasing their importance.
3. Nanomaterials
Nano is a prefix used to express the idea of the billionth part of something. For example, nanometres or nanoseconds indicate measures of a billionth of a metre, and a billionth of a second, respectively. Nano-level numbers can thus be written as a value $x \times 10^{-9}$ to show their magnitude [3].

3.1. Principles of Nanotechnology [5]
1- Discovering new properties including increased longevity and better material survival.
2- Better material characteristics in terms of reduced size, increased strength, reduced weight, reduced costs, and less energy consumption.
3- Allowing materials to be free from impurities and defects.

3.2. Nano architecture.
Nano architecture is the process of combining nanotechnology with architecture to produce buildings that interact with the surrounding environment more effectively; it is thus also a way to change design thinking in a positive manner, and to produce buildings that last longer than before that are also environmentally friendly, as shown in Figure 1 [6].

3.2.1. Nano architecture used in conservation and restoration:
1- Self-Cleaning Mechanisms (Lotus Effect, per Figure 2)
   Surfaces designed with nanomaterials for self-cleaning include simple items such as nails with wax heads as in Figure 3, textures that do not allow water droplets to touch the surface as in Figure 4, and non-staining surfaces as shown in Figure 5 [7].

Figure 1. Changing ways of thinking

Figure 2. Lotus Effect[7]

Figure 3. Nails with wax heads[7].
Figure 4. Self-cleaning surface [7]  

Figure 5. Ara Pacis Museum exterior view[7]

2- Self-cleaning mechanisms (Photo catalysis)
-Hydrophilic surfaces that allow deposited dirt to broken down; this then lies loosely on the surface as in Figure 6 until a water film washes the dirt away. UV light and water are required to achieve this effect, which nevertheless reduces maintenance requirements for external surfaces [8].

![Figure 6. The formation of water droplets on traditional tiles; these dry out, leaving dirt behind. For hydrophilic surfaces, after photocatalysis, the water forms a membrane that runs out, taking any soil deposits with it [8].](image)

3- Air-purification:
 Pollutants and odours are broken down into their constituent parts; while further ventilation is still required, this improves air quality.

![Figure 7. European Headquarters., German, plasterboard air purifier. [9]](image)  

![Figure 8. Exterior façade (Kaldewei Kompetenz-center). [9]](image)

Indoors, such air purification technology is increasingly being used within textiles and paints, as shown in Figure 7, while outdoors, the air-purifying capacity of photocatalytic concrete is now used to provide a means of combating air pollutants as shown in Figure 8 [9],[10].

3.2.2. Types of nanomaterials used in architecture.
 Nanomaterials may be either organic or inorganic,

1- Thermo-Shield is an energy-saving and atmosphere-resistant coating consisting of microscopic ceramic balls in a suspended state, produced in a liquid form; this is made of synthetic rubber, polymers and inorganic dyes, and the resulting the paint can be applied to bricks [2], to preserve the structure, as seen in Figure 9, especially in hot and dry climates. It provides excellent protection against weather factors and prevents the penetration of brick particles [11]
2- Fire protection coating blister is a liquid coating made from organic solvents, polymers, and inorganic and modified dyes that improve heat resistance. It can be also be applied to bricks to isolate the surfaces from water and thus reduce environmental impacts, increasing the protection of surfaces against corrosion.

3- Self-healing coatings offer transparent coating techniques to give buildings greater durability and resilience for the longest possible period; these are made of polyurethane matrices [12].

3.2.3. Examples of current nanotechnology applications:
1- The use of calcium silicate hydrate gel (C-S-H)
2- The addition of titanium dioxide (TiO2).
3- The addition of Nano Silica.

As the main materials used in archaeological buildings in Iraq are bricks and wood in terms of the structural frames, with plaster as a finishing material, this research sought to examine the impact of nanotechnology in the treatment of these materials to help develop solutions to contribute to preserving the permanence of buildings of this type with significant archaeological and cultural value [10].

4. Archaeological buildings
Archaeological buildings are buildings that last for more than a hundred years and which have a certain value in terms of being symbols of cultural identity; the values of such buildings are architectural, historical, aesthetic, and social in addition to spiritual, political and symbolic [13].

4.1. The importance of preserving the permanence of archaeological buildings
These monuments are clear structures that represent the heritage of their country and its built environment. This makes it necessary to preserve the durability of these buildings to ensure their survival, including facilitating the repair of parts that are damaged or eroded as a result of time and environmental conditions. Many procedures and measures have been applied to conservation operations in previous periods in response to the exposure of archaeological buildings to many factors and conditions that can cause erosion, damage, or the appearance of signs of moisture and heat on the external surfaces [9].

4.2. Restoration and conservation operations
Restoration operations can be done on individual damaged elements, for example, if there is damage to a dome, minaret, wall, or any other element of an archaeological building; a partial restoration that
treats only a part of the element, such as the mortar, is also possible. Each such operation requires different procedures, but overall, they can be divided into restoration operations as shown in Figure 10 and conservation operations as in Figure 11, as these require very different processes [14]. Conservation refers to the maintenance of antiquities to preserve them from damage, to determine their physical and chemical properties, and to determine the severity of any damage that has already occurred and its various manifestations on a practical basis. There are several modern types of conservation application, including mechanisms for predicting the behaviour of materials [2], as well as nanotechnology applications.

Figure 10. Urban fabric of old Najaf city. Reference: Alnajaf Madinaty Homepage

Figure 11. Decoration on façades Reference: Alnajaf Madinaty Homepage

4.3. Nanotechnology and its effect on preserving the permanence of archaeological buildings
The most important advanced treatments may be those used to protect the surfaces of buildings permanently from destruction by environmental factors and user action by means of Cloud Nano layers; these are used to create a coating material that prevents dust, dirt, and water from penetrating the materials, as well as resisting other factors such as graffiti. These materials are UV-resistant and do not allow contaminants to stick to the surface of buildings, offering greater protection with the help of calcium hydroxide nanoparticles [13].

The continuous development of nanostructures and the ongoing study of physical-chemical processes within the nanometre range have led to the development of new methods to slow down the decomposition of archaeological structures and even to restore damage caused by inappropriate restoration operations [14]. Purification, desalination, and standardisation of different types of building materials can be done by applying nanoparticle suspensions; hydroxide Nano-emulsions such as calcium, barium, and magnesium; carbonates; or, in some cases, sulphates. The use of calcium hydroxide nanoparticles is probably the most widespread application of nanomaterials in heritage care, especially with regard to hardening limestone building materials such as plaster and solid limestone, in conjunction with titanium dioxide. This has been shown to be successful in combating biological factors and surface pollution as well as increasing the UV-resistance of building materials [2].

4.4. Nano applications at the level of maintenance and restoration
One of the applications of nanoscale materials at the maintenance level is in the process of cleaning the external and internal surfaces of heritage buildings; this can be done using nanotechnology such as Radio Frequency (RF) plasma, a glowing substance created using oxygen and hydrogen as the input agent gases, which can remove some mineral stains (iron and copper) that frequently affect the surfaces of heritage buildings built of brick, as well as organic sources of staining such as soot. The cleaning of antique buildings is a basic process that has attracted a wide range of technologies, and applications range from large facades to very small areas: an example of the application of
nanotechnology to the process of cleaning heritage sites is offered by the cleaning the place of Prince Yousif Kamal in Nagaa Hammadi in Qena, Egypt as shown in Figure 12 [9].

![Figure 12. Palace of Prince Yousif Kamal in Nagaa Hammadi [9]](image)

In terms of restoration with nanotechnology applications, treatments are generally localised, being based on the state of the building and the state of wear, with treatment carried out using techniques and materials on site based on an expert’s decision. Nanotechnologies are generally used to ensure minimal interference during restoration work, as required by multiple international conventions, to preserve the historical value of such buildings. These techniques include reinforcement with carbon fibre slices to support domes built with blocks, and one of the best examples of this is at the Al-Aini School in the Al-Azhar District of Cairo, as shown in Figure 13, where nanotechnologies were used in the brick dome restoration to provide reinforcement with carbon fibre slices. These materials and technology were suited to the dome's structural condition and offered the elasticity required to create alignment with the curvature of the dome [15].

![Figure 13. Dome support model for the Al-Aini School using carbon fibre](image)

Among the historical buildings treated with nanotechnology at the level of either total or partial restoration is the local mosque in Al-Rashid City in Egypt, shown in Figure 14. This mosque had suffered deformation in some parts of its walls and other architectural elements exposed to destructive factors, and the bricks were thus treated with a coating of nanomaterials applied by brush; the polymer silicone and acrylic solution was devised at a specific concentration to create protective layers for the external surfaces, increasing waterproofness, and offering protection to the original materials from environmental factors such as rain and air pollution. The mortar was also treated by adding dispersed nanoparticles (5Nano-silica) in a dispersion medium, one of the important measures required to achieve the correct coherence of brick internal structures in historical buildings. Incorporating materials must take into account their ability to improve both the physical and mechanical properties of the building and their compatibility with the nature of the brick fabric, however [6].
4.5. Bricks in archaeological buildings in Iraq
The production of bricks has consistently improved through the ages. Bricks mixed with the tar to increase their resistance to water and moisture were used in the tiling of the ziggurat of the moon goddess Nana in Ur, while glazed bricks with bright colours and regular rims were used in the city of Babylon and its temples. Bricks used in Islamic times in the decoration of the walls of mosques and shrines are known today as Karbala tiles, as shown in Figure 15. The main component of any such brick is clay, however, which is a product of crumbling volcanic rocks that generally consists of aluminium silicates, crystalline silicates (silicon dioxide), mica, and multiple additional silicon compounds. Clay mortar, it is also used to bond these building blocks [13].
4.5.1. Problems with bricks in the architectural heritage of Najaf.

The exterior surfaces, foundations and the lower part of walls are often affected by groundwater, especially in Iraq, where most of the archaeological buildings are located within sedimentary plain regions heavily affected by fluctuations in water. This causes cycles of moisture and drought to affect those foundations and walls that are exposed, leading to physical erosion. As historical buildings are generally built of bricks and plaster, porous materials, dark spots and salt flowers tend to form on the surface of the bricks. This emphasizes the role of rain, which is one of the damage factors that most significantly affects building materials such as those used in monumental buildings, as these salts are moistened and crystallized after droughts, as shown in Figure 16, leading to weakening of the internal structure of these materials [6].

![Figure 16. Salt flowers on the surface of bricks during the restoration of the Kufa Mosque](image)

Heritage buildings in Najaf are affected by various weathering factors, especially salts from salty groundwater and the salty environment that result from the evaporation of water in the air; these have a negative influence on the external surfaces of heritage buildings, though groundwater is considered the most important source of rapid impact on local building materials, including bricks, as buildings in Najaf tend to have multi-level basements that reach as much as 20 m underground, known as Al-Sin. It further suffers from groundwater due to the fact that the soil is sandy in many areas; Najaf soil is derived from the rocks of the region, which date back to ancient geological eras when layers of limestone, mud and sand accumulated [14]. Thus, in addition, the changing nature of Najaf soil, from gypsum and limestone on the northern side of Najaf to the sandy limestone rock on the southern side means that the dust-laden winds influence heritage buildings by accelerating erosion and spreading pollutants onto the external surfaces of buildings. This is heightened by the exposure of the region, especially the old city, to winds laden with dust coming from the western side in different periods of the year, as shown in Figure 17.

![Figure 17. The city of Najaf](image)
In the Sassanid era, Najafis used Nora as a binder instead of or alongside plaster; this is a basic compound that directly forms calcium carbonate, but which contains a quantity of silica (SiO2) and aluminium oxide (Al2O2). Nora thus has the ability to harden underwater, after being mixed with ash, and it was fermented with water in special tanks and used for foundations and building segments that would be exposed to water and moisture, as it acts as a moisture barrier. Plaster remained the main bonding material (CaSO42H2O), used in addition to structural materials and thus not usually exceeding 30% by weight. However, plaster was used as a supplement to buildings, and to cover the internal walls of buildings extensively, as well as in the outer walls when it was not possible to use bricks in most Najaf homes, however.

The basic material used in construction at the time was brush brick (Farshi), similar to modern brick in composition while differing in form and size. Treated Farshi are heat and moisture resistant due to a lack of pores, and this material was thus used for cladding facades and decoration in addition to its use in floors. In addition to its resistance to moisture in the winter, it also acts as a thermal insulator in the summer [16].

![Figure 18. Khan Al-Shilan in Najaf during restoration: Khan Shilan Archives.](image)

4.5.2. Khan Al-Shilan. Khan Al-Shilan, shown in Figure 18 is one of the most important buildings in Najaf city. It was built between 1890 and 1895 as a rest and overnighting area for visitors to the shrine of Imam Ali Ibn Abi Talib (AS), which is located on the outskirts of Al-Buraq, one of the old Najaf localities. The Khan walls and domes were built of Farshi, with bricks used for the floors and exterior walls, with plaster and Nora used for bonding. The building underwent multiple restorations in the 1970s and 1990s, though the building was reused as a market, which heavily affected its deterioration.
The latest restoration process was applied in 2010 in an attempt to return the building to its former appearance to facilitate its use as a museum of historical events in the city of Najaf.

The materials used for the restoration were the traditional materials (Farshi, plaster, and Nora). However, these materials need constant maintenance and ongoing restoration because of the problem of the exposure of the building to moisture from groundwater and sewage, as shown in Figure 19. It is thus preferable to use modern materials and technologies to increase the resistance of materials to weather factors such as humidity, which is the main cause of damage to building materials in heritage buildings, and thus to both increase the life of the building and reduce the costs of continuous maintenance. This is sometime resisted, however, as the building loses some of its originality due to modern material and construction techniques being used in restoration, which somewhat contradicts the conservation purposes, due to the lack of expertise in this field.

Figure 19. Damage in the lower parts of the wall in the basement on 7/5/2020.

4.5.3. Nanomaterial effects on brick preservation.

The main material forming bricks is clay, which consists of aluminium silicate, crystallized silicon dioxide, mica, and various silicone compounds; all of these substances are affected by water and citric acid, which slowly degrades them alongside other natural erosion factors [13]. Nanotechnology applications can be used strengthen and support bricks and mortar, rectifying the porous nature of these materials that causes them to absorb rainwater and dust easily, which causes performance deterioration and mould growth. Two main types of treatment are available

1- The manufacture of aerated bricks (cellular), bricks with a porous structure made from recycled stone wastes resulting from stone processing; this has exceptional properties when used in buildings due to its resistance to moisture and dust. These bricks were developed by adding an environmentally friendly aqueous solution with TiO2 nanoparticles, generated using hydrothermal reactions, to coat the porous bricks to obtain a super water-resistant surface. Figure 20 shows highly dispersive TiO2 nanoparticles used to coat an aerated brick surface by dip-coating, creating a rough epidermis with TiO2 nanoparticle chunks. The TiO2 nanoparticles are then covered with TEOS to undergo hydrolysis, forming –OH terminal groups on the surface while the –Si-OH sets in the hydrolysed PFOTS are dehydrated, causing the –OH sets on the TiO2 surface to self-collect and to develop a hierarchical architecture. This artificial surface modified with super-hydrophobic sets allows high water repellence, offering major potential for self-cleaning and water-proofing applications. This is thus a promising technology for large-scale building application, further improving the performance of bricks with regard to water resistance [17].
Modified highly dispersed TiO2 nanoparticles prepared using a superior waterproof suspension act with the cell brick to create a water-repellent surface; this feature can prevent the bricks from being affected by rainwater and corrosion, and thus maintains outstanding performance and appearance for buildings, as shown in Figure 21. The design of cellular bricks is intended to meet the needs of waterproofing through the use of nanomaterials in an environmentally friendly way as well as offering a strategy for waste recycling and expanding the application of superior waterproofing technology.

2- Bricks already present in buildings can also be coated with the aforementioned nanomaterials [18] to preserve and increase resistance to weathering. This is applicable whether the brick is used as a finishing material for buildings, or as decorative brick in the façades of heritage buildings, or even painted with the finishing materials or plaster.

These applications highlight the importance of nanomaterials in extending the permanence of brick-built buildings, and the availability of treatments at different stages using varying mechanisms, processes, and materials that allow restorers to protect antique buildings from collapse and damage, and to repair the damaged ones. The materials used are either of modern manufacture, which meet the specifications of the old materials formally while increasing the properties of permanence, or the existing old materials after processing with nanomaterials.

5. Summary
Nanotechnologies appear likely to contribute significantly to preserving the permanence of archaeological buildings in Iraq in general, and the archaeological structures of Najaf in particular, especially in terms of combatting dust problems without affecting the aesthetic, formal and physical properties of the relevant buildings. This technology has very broad capabilities, particularly in terms of mixing the technology and materials used for the buildings with materials used in manufacturing new buildings through the use of nanoparticles for treatment and the modification of the characteristics of these new materials. This contributes to creating environmentally-friendly buildings, reducing the costs of cleaning, maintenance, and restoration as well as reducing initial harmful environmental impacts. In particular, many such new building materials depend on the recycling of damaged materials and the development of passive resistance to harmful environmental factors. This research thus highlights the new technological capabilities offered by the use of nanotechnologies that can be used to keep historic structures sustainable and completely safe, based on choosing the most suitable materials for the required treatment of brick.
6. Results
1- The permanence of material depends on human, environmental, and temporal factors.
2- The most important method of increasing durability in modern times is nanotechnology.
3- The most important applications of nanostructures in buildings are self-cleaning techniques, air purification, and optical stimulation.
5- Nanomaterials may be structural, complementary, paint, or insulating. These all work to resist fire and heat and are characterised by the ability to provide excellent protection from weather conditions.
6- Nanotechnology and nanomaterials greatly influence the preservation and permanence of brick.
7- Nanomaterials and nanotechnologies offer optimal treatments for archaeological structures that do not affect the original building materials in terms of their external or physical appearance.
8- The most important applications for the maintenance of heritage buildings is predicting the behaviour of materials.
9- Coating bricks with nanomaterials such as polymer silicone and acrylic solution provides high protection for external surfaces.
10- Treating mortar in archaeological buildings by adding dispersed nano granules (Nano-silica) offers a remedy for crumbling.
11- Air bricks are a new type of brick that is contributing to major developments in the construction field.
12-The possibility of using TiO2 nanoparticles as basic material, either in manufacturing new types of brick or as a coating material to improve the performance of the bricks in archaeological buildings, is very strong.

7. Conclusions
1- Nanotechnology contributes to increasing the durability of historical buildings and transforming them into more environmentally friendly structures.
2- The choice of appropriate nanotechnology and materials for the preservation of brick material is related to the determination of harmful environmental factors.
3- Salt is the main reason for the deterioration of most heritage buildings.
4- Calcium hydroxide and TiO2 are the most effective substances in terms of protecting buildings from biological effects.

8. Recommendations:
1 - Further studies to determine the reasons for the deterioration of heritage buildings and appropriate methods of restoration are required.
2- A commitment to meeting international conventions is required.
3- Materials used in restoration must be rigorously tested and selected so as not to affect the authenticity of the buildings.

References
[1] Ion R, Doncea S, and Carutiu D 2017 Nanotechnologies in Cultural Heritage - Materials and Instruments for Diagnosis and Treatment. https://www.intechopen.com
[2] Hemeda S 2018 D Int J Conserv Sci. The effectiveness of Nano materials and Nano-modified polymers for preservation of historic brick masonry in Rashid, Egypt 57 844 http://www.ijcs.uaic.ro
[3] Aljenbaz A, Çağnan, Ç 2020 European Journal of Sustainable Development Evaluation of Nanomaterials for Building Production within the Context of Sustainability 91 53-53,3,5
[4] Palladio A and Adolf K The four books of architecture tr. Isaac ware New York.
[5] Hussein 2017 N. the durability of the material and its effect on the monumentality of architecture 20 14-6
[6] Fouad F and Ibrahim M 2013 *Advanced Materials Research* Nano Architecture and Sustainability *671* pp. 2298-2303. Trans Tech Publications Ltd.46-64 https://doi.org/10.4028/www.scientific.net/AMR.671-674.2298

[7] El-Samny F 2008 *Nano Architecture* Alexandria Univ. Egypt 28 9 16

[8] Swagata B, Dionysios D, Suresh C Pillai 2015 *Applied Catalysis B: Environmental* Self-cleaning applications of TiO2 by photo-induced hydrophilicity and photocatalysis *176* 379-400 www.elsevier.com/locate/apcatb

[9] El-Gohary M and Metawa A 2016 *International Journal of Conservation Science* cleaning of architectural bricks using rf plasma. I. Metallic stains 7 3 11-31

[10] Basauony M, A EL Kattan A, S Atwa M 2019 *Al-Azhar University Engineering Sector* Applications of Nanotechnology in Architecture *1453*1729-1739 30 11 31 12

[11] Arafha R 2016 *Al Azhar University Engineering Sector* Architecture and nanotechnology *11* (39) 904-912 5

[12] Zagorskas J, Zavadskas E, Turskis Z, Burinskienë, M, Blumberga A, and Blumberga D 2014 *Energy and buildings* Thermal insulation alternatives of historic brick buildings in Baltic Sea Region *78* 35-42 36 www.elsevier.com/locate/enbuild

[13] Tahir M 2016 *Architecture and Construction* Effects of Sustainable Restoration by Nano-Technology, Sh. Rajai Univ. S.S. Publications 2, Tehran 105 -113

[14] Al-ansari A 2016 *Archeological and Historical Studies* The Impact of Natural Factors on Heritage Buildings (Old City of Samarra) Al-Mallawayh 3 Issue 6 15

[15] Sabry Y 2016 *J Al Azhar University Engineering Sector* materials technology applications in carbon fiber reinforcement with architectural heritage projects. Al-Ainy Archaeological School in Cairo *11*38 331-342 27

[16] Al-Modhafar M 2011 *Al-Najaf city* The genius of meaning and the sanctity of the place Iraq 132-126

[17] Al-Khalidi H 2017 *Heritage Buildings in Najaf* 755

[18] Li T, Zeng S, Ji Y, Shen B, Wang Z, Zhong H, and Wang S 2019 *Applied Sciences* Waterproof aerated bricks from stone powder waste through nano-TiO2 structured hydrophobic surface modification *913* 2619 5