Nanotechnology in Archeology

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Abstract:

Nanotechnology has become at the forefront of the most important and exciting fields in physics, chemistry, biology, engineering, archaeology and many other fields. nanotechnology will be one of the main techniques in the future. the term "nanotechnology" refers to the material manufacturing techniques that its internal granule's dimensions range from 1-100 nanometers (nm).The process of preserving and maintaining antiquities is one of the most complex topics in materials science because it requires an overlap of multidisciplinary expertise ranging from architecture and materials developments in materials science have shown that many of the complex problems that cultural heritage suffers from can be solved very effectively with the intervention of chemistry, physics and other various sciences.Recently, many nanomaterials have been applied in the treatment and maintenance of many archaeological materials (artifacts) of different types, whether located in museums or those found in open environments in archaeological sites in order to improving their properties, strengthening and protecting them against various damage factors. Nanomaterials have multiple advantages by strengthening or cleaning which started to help solving many problems of antiquities which made the new nanomaterials of great importance in the development of many new applications in conservation of antiquities (monuments and artifacts).

Key words: Nanotechnology, Nanomaterials, Nanometers, Materials Science, Cultural Heritage, Museums.

تقنية النانو وعلم الآثار

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مستخلص:

أصبحت تقنية النانو في طليعة المجالات الأكثر أهمية في الفيزياء والكيمياء والأحياء والهندسة وعلم الآثار والعديد من المجالات الأخرى، وستكون تقنية النانو إحدى التقنيات الرئيسية في المستقبل. يشير مصطلح «تقنية النانو» إلى تقنيات تصنيع المواد التي تتراوح أبعاد حبيباتها الداخلية من 100-1 نانومتر.تعد عملية الحفاظ على الآثار وصيانتها من أكثر المواضيع تعقيدًا في علم المواد لأنها تتطلب تداخل خبرات متعددة التخصصات بدءًا من الهندسة المعمارية والمواد وقد أظهرت التطورات في علم المواد أن العديد من المشكلات المعقدة التي يعاني منها التراث الثقافي و يمكن حلها بفعالية كبيرة مع تدخل الكيمياء والفيزياء وغيرها من العلوم المختلفة.وقد تم - في الآونة الأخيرة- تطبيق العديد من المواد النانوية في معالجة وصيانة العديد من المواد الأثرية (القطع الأثرية) بأنواعها المختلفة سواء الموجودة في المتاحف أو تلك الموجودة في البيئات المفتوحة في المواقع الأثرية وذلك لتحسين خواصها وتقويتها وحمايتها من عوامل التلف المختلفة. تتمتع المواد النانوية بمزايا متعددة من خلال التقوية أو التنظيف والتي بدأت تساعد في حل العديد من مشاكل الآثار مما جعل للمواد النانوية الجديدة أهمية كبيرة في تطوير العديد من التطبيقات الجديدة في مجال حفظ وترميم وصيانة الآثار.

الكلمات المفتاحية: تقنية النانو، المواد النانوية، نانومتر، علم المواد، التراث الثقافي، المتاحف

Introduction

Over the past few years, a little word with big potential has been rapidly insinuating itself into the world's consciousness. That word is "nano." It has conjured up speculation about a seismic shift in almost every aspect of science and engineering with implications for ethics, economics, international relations, day-to-day life, and even humanity's conception of its place in the universe (Mark Ratner, Daniel Ratner, 2002, 7).

On December 29, 1959 at the California Institute of Technology, Nobel Laureate Richard P. Feynman gave a talk at the Annual meeting of the American Physical Society that has become one classic science lecture of the 20th century, titled "There's Plenty of Room at the Bottom." He presented a technological vision of extreme miniaturization in 1959, several years before the word "chip" became part of the lexicon. He talked about the problem of manipulating and controlling things on a small scale. Extrapolating from known physical laws, Feynman envisioned a technology using the ultimate toolbox of nature, building nanoobjects atom by atom or molecule by molecule. Since the 1980s, many inventions and discoveries in fabrication of nanoobjects have been a testament to his vision. Nanotechnology literally means any technology done on a nanoscale that has applications in the real world (B. Bhushan, 2004, IX).

Nanotechnology encompasses production and application of physical, chemical and biological systems at size scales, ranging from individual atoms or molecules to submicron dimensions as well as the integration of the resulting nanostructures into larger systems. Nanofabrication methods include the manipulation or self-assembly of individual atoms, molecules, or molecular structures to produce nanostructured materials and sub-micron devices. Micro- and nanosystems components are fabricated using top-down lithographic and nonlithographic fabrication techniques. Nanotechnology will have a profound impact on our economy and society in the early 21st century, comparable to that of semiconductor technology, information technology, or advances in cellular and molecular biology. The research and development in nanotechnology will lead to potential breakthroughs in areas such as materials and manufacturing, nanoelectronics, medicine and healthcare, energy, biotechnology, information technology and national security. It is widely felt that nanotechnology will lead to the next industrial revolution (B. Bhushan, 2004, V).

The word “Nano” means dwarf in Greek language. Use it as a prefix for any unit like a second or a meter and it means a billionth of that unit. A nanosecond is one billionth of a second. And a nanometer is one billionth of a meter—about the length of a few atoms lined up shoulder to shoulder. A world of things is built up from the tiny scale of nanometers (J. Dutta & H. Hofmann, 2005, 7).

Nanoscience is, at its simplest, the study of the fundamental principles of molecules and structures with at least one dimension roughly between 1 and 100 nanometers. These structures are known, perhaps uncreatively, as nanostructures. Nanotechnology is the application of these nanostructures into useful nanoscale devices. That isn't a very sexy or fulfilling definition, and it is certainly not one that seems to explain the hoopla. To explain that, it's important to understand that the nanoscale isn't just small, it's a special kind of small (see figure1).

Anything smaller than a nanometer in size is just a loose atom or small molecule floating in space as a little dilute speck of vapor. So nanostructures aren't just smaller than anything we've made before, they are the smallest solid things it is possible to make. Additionally, the nanoscale is unique because it is the size scale where the familiar day-to-day properties of materials like conductivity, hardness, or melting point meet the more exotic properties of the atomic and molecular world such as wave-particle duality and quantum effects. At the nanoscale, the most fundamental properties of materials and machines depend on their size in a way they don't at any other scale. For example, a nanoscale wire or circuit component does not necessarily obey Ohm's law, the venerable equation that is the foundation of modern electronics. Ohm's law relates current, voltage, and resistance, but it depends on the concept of electrons flowing down a wire like water down a river, which they cannot do if a wire is just one atom wide and the electrons need to traverse it one by one. This coupling of size with the most fundamental chemical, electrical, and physical properties of materials is key to all nanoscience. A good and concise definition of nanoscience and nanotechnology that captures the special properties of the nanoscale comes from a National Science Foundation document edited by Mike Roco and issued in 2001:

One nanometer (one billionth of a meter) is a magical point on the dimensional scale. Nanostructures are at the confluence of the smallest of human-made devices and the largest molecules of living things. Nanoscale science and engineering here refer to the fundamental understanding and resulting technological advances arising from the exploitation of new physical, chemical and biological properties of systems that are intermediate in size, between isolated atoms and molecules and bulk materials, where the transitional properties between the two limits can be controlled (Mark Ratner, Daniel Ratner, 2002, 11-12).

Nanotechnology is a new word, but it is not an entirely new field. Nature has many objects and processes that function on a micro- to nanoscale . The understanding of these functions can guide us in imitating and producing nanodevices and nanomaterials.

Billions of years ago, molecules began organizing themselves into the complex structures that could support life. Photosynthesis harnesses solar energy to support plant life. Molecular ensembles are present in plants, which include light harvesting molecules, such as chlorophyll, arranged within the cells on the nanometer to micrometer scales. These structures capture light energy, and convert it into the chemical energy that drives the biochemical machinery of plant cells. Live organs use chemical energy in the body. The flagella, a type of bacteria, rotates at over 10,000 RPM (B. Bhushan, 2004, 2).

This is an example of a biological molecular machine. The flagella motor is driven by the proton flow caused by the electrochemical potential differences across the membrane. The diameter of the bearing is about 20–30 nm, with an estimated clearance of about 1 nm. In the context of tribology, some biological systems have anti-adhesion surfaces. First, many plant leaves (such as lotus leaf) are covered by a hydrophobic cuticle, which is composed of a mixture of large hydrocarbon molecules that have a strong hydrophobia. Second, the surface is made of a unique roughness distribution. It has been reported that for some leaf surfaces, the roughness of the hydrophobic leaf surface decreases wetness, which is reflected in a greater contact angle of water droplets on such surfaces (B. Bhushan, 2004, 2).

Nanotechnology is a term that has entered into the general and scientific vocabulary only recently but has been used at least as early as 1974 by Taniguchi. Nanotechnology is defined as a technology where dimensions and tolerances are in the range of 0.1-100 nm (from size of the atom to about the wavelength of light) play a critical role. This definition is however too general to be of practical value because it could as well include, for example, topics as diverse as X-ray crystallography, atomic physics, microbial biology and include the whole of chemistry (J. Dutta & H. Hofmann, 2005, 9).

Nanotechnology has become at the forefront of the most important an d exciting fields in physics, chemistry, biology, engineering, archaeology and many other fields. Since, it has given great hope for scientific revolutions in the near future that will change the direction of technology in many applications in different fields of knowledge, so nanotechnology will be one of the main techniques in the future.

The antiquities of any country are considered as precious treasures of its civilizations. Antiquities are looked at as the visible and readable reference for those ancient civilizations, antiquities could also be a documented base for any new achievements of mankind. Given the importance of this heritage, there are many academic and administrated institutions interested in preserving, maintaining and documenting it. Various covenants were also created between countries for this reason. However, there are many problems facing these heritage sites of different types which affect their lifespan as well as their efficiency. These problems are either environmental, economic, or social, resulting from the lack of cultural awareness of those who deal with these cultural heritage sites.

The process of preserving and maintaining antiquities is one of the most complex topics in materials science because it requires an overlap of multidisciplinary expertise ranging from architecture and materials technology to analytical chemistry and advanced physics. Recent developments in materials science have shown that many of the complex problems that cultural heritage suffers from can be solved very effectively with the intervention of chemistry, physics and other various sciences.

Recently, many nanomaterials have been applied in the treatment and maintenance of many archaeological materials (artifacts) of different types, whether located in museums or those found in open environments in archaeological sites in order to improving their properties, strengthening and protecting them against various damage factors. Nanomaterials have multiple advantages by strengthening or cleaning which started to help solving many problems of antiquities because nanoparticles of new properties and different from those with a larger partial size "more than 100 nanometers" which made the new nanomaterials of great importance in the development of many new applications in the field of treatment and conservation of antiquities (monuments and artifacts).

Therefore, it has become necessary to search in modern technical methods and materials used in maintenance and restoration operations, as well as strengthening and protection processes, especially those that follow the nanotechnology method due to the success of this technology in all fields and various sciences through its evaluation and study of its efficiency without violating the heritage using it with full confidence in the sustainability of the inheritance through it.

Nanomaterials in Art and Cultural Heritage

The ruby-red color of many stained-glass windows from the Medieval era was a consequence of embedded nanoscale metallic particles within the glass (see figure 2). These rich colors in stained glass, like the metallic sheens associated with naturally embedded nanoparticles in many ceramics, were appreciated and highly valued by artisans, patrons, and laymen alike. Stained-glass artisans sometimes treasured small vials of materials that we know were metallic oxides, obtained from special mines and handed down within their families with careful instructions on how to work with them, when the size of material particles is reduced to the nanoscale, optical properties—particularly color— can be dramatically affected. In such cases, the wavelength of light is very close to the size of the particles themselves, which causes the way that color is reflected, scattered, or absorbed to be dependent on the size and shape of the nanoparticles themselves (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 29).

There was no scientific understanding of these phenomena at the time, nor were there deliberate attempts to produce what we now know as nanomaterials.

One of the most interesting specimens is the Roman-era Lycurgus cup. Roman glassware has often been used to characterize the material cultural achievements of the late Roman Empire. Glassproducing techniques were highly developed, and workmanship was superb. In the Lycurgus cup, now housed in the British Museum, the 324 AD victory of Constantine over Licinius in Thrace was represented through the death of an enemy of Dionysius, Lycurgus, who is shown being overcome by vines. The most remarkable characteristic of this goblet is that under normal external lighting conditions the glass appears green, but when lighted from within, it assumes a strong red color (see figure3) (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 30).

The Lycurgus cup has now assumed an almost iconic status in the nanomaterial field as an early example of the surface plasmon phenomenon, in which waves of electrons move along the surface of metal particles when light is incident onto them.

Analyses have demonstrated that the glass in the Lycurgus cup contains rather small amounts of gold powder embedded within it (on the order of 40 parts per million). These tiny metallic particles suspended within the glass matrix have diameters comparable to the wavelengths of visible light. As a consequence, a form of plasmonic excitation (an oscillation of the free electrons at the surface of a metal particle at a certain frequency) can occur. Light reflections are enhanced as the waves are highly absorbed and scattered, reducing transmission. This absorption has an orientational dependence. Interestingly, other colors aside from the red and green seen in the Lycurgus cup could be achieved by altering metal particle sizes. In the cup, however, color properties depend primarily on reflection when the light is external to the cup and on absorption and transmission when the light source is internal (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 30).

Many Medieval and Renaissance ceramics have surfaces characterized by a remarkable iridescent metallic shine (see figure4). This form of ceramic decoration, a type of luster, appeared in the Middle East in the ninth century or before and subsequently spread through Egypt, Spain, and other countries. A particularly fine period of development occurred in Spain with Hispano-Moresque ware, a glazed ceramic made by Moorish potters largely at Málaga in the 15th century and later at Manises near Valencia in the 16th century (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 30-31).

To produce this type of lusterware, a glaze was first applied over a design and the piece fired to produce a thin, hard coating. Glazes were based on dry powdered minerals or oxides, which commonly included tin and copper. After the first firing, the luster coating, consisting of metallic pigments (normally copper or silver compounds) mixed with clays, was brushed on over the glaze. Then the piece was fired again but at a lower temperature and within a reducing atmosphere (a condition whereby a reducing agent chemically causes a change in a material with metallic compounds to a metallic state by removing nonmetallic constituents as it is itself oxidized by donating free electrons). Afterward the piece was cleaned and polished to reveal the resulting metallic sheen (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 31).

Later examples include the "tin-glazed" pottery of 15th and 16th century Italy and the "copper glazed" lusterware porcelains of Wedgwood in early 19th century England. Several studies of medieval lusterware via transmission electron microscopy (TEM) have been undertaken to understand the composition and microstructure of luster. Results have clearly indicated that various luster characteristics can be described in terms of the presence of different levels of silver or copper nanoparticles within the glassy matrix. The associated surface plasmon effects cause the appealing metallic sheen to develop. Again, though the artisans producing lusterware lacked an understanding of the chemical processes that achieved the optical effects and were unaware that their empirical processes led to the creation of nanoparticles, the craft-based development of the requisite knowledge was remarkable.

Similarly intriguing was the development of the beautiful blue paint found in the murals and pottery of the ancient Mayan world (see figure5). The Mayan blue has long been admired for its marvelous color qualities as well as its inherent resistance to deterioration and wear over long periods of time.

Nanotechnology for Cultural Heritage Preservation:

Cultural Heritage is an invaluable patrimony of society, embracing virtually all the artifacts, works of art, objects and intangible attributes that convey artistic, historical or anthropological values. The preservation of such patrimony is the only way to effectively transfer it to future generations, in order to continue the intellectual progress of society while conserving the ancient and modern cultural traditions that characterize our world. Besides intellectual and aesthetic aspects, the preservation of Cultural Heritage allows its valorization and exploitation, with considerable economic advantages. Given its importance, it is not surprising that Cultural Heritage has gathered in the last decades the attention of different professional characters that provided approaches to address numerous conservation issues. In fact, the variety of degradation phenomena that affect works of art mirrors the vast array of materials that have been used by mankind since early ages. Therefore both conservators and scientists are involved in finding effective solutions to counteract aging processes due to the action of light, temperature, relative humidity and microorganisms, chemical degradation and physical erosion, or to anthropic causes such as industrial pollution, vandalism, or the mere handling of artifacts. Moreover, restoration interventions can prove—and have often proven—detrimental in the long term whenever scientific criteria are not followed. Based on the experience acquired in the past decades, the use of products that exhibit as much as possible the same physico–chemical properties of the treated artistic or historical substrates (i.e. “compatible” materials) has been highlighted as a valid principle to grant the durability of treatments and to minimize drawbacks. For instance, the treatment of carbonate-based wall paintings with low-compatibility materials such as synthetic organic coatings and adhesives can lead to the alteration and degradation of the painted surface, and compatible inorganic materials have been successfully proposed as an alternative for the consolidation of these works of art (Piero Baglioni , David Chelazzi , Rodorico Giorgi, 2015, 1).

A multidisciplinary approach to conservation issues is the key for a successful intervention, and the cooperation between scientists, conservators, art historians etc. is fundamental for the refinement of restoration materials and techniques.

Finally, a "cure" must be found, meaning that tools and materials are to be developed to counteract, stop, and ideally revert the degradation process. Regarding the latter task, which is the focus of this Compendium, materials science has provided a fundamental contribution, and in particular colloids science and nanosciences have emerged in the last four decades as fields of paramount importance, being the source of concepts and tools that have improved dramatically the effectiveness, reliability and durability of restoration interventions (Piero Baglioni , David Chelazzi , Rodorico Giorgi, 2015, 2).

Conservation:

Conservation and restoration of works of art and other forms of cultural heritage have been a constantly evolving pursuit in which nano-based techniques play increasingly valuable roles (see figures 6&7). A great number of factors can play a role in the degradation of artworks. For instance, microbial growth can have a range of detrimental effects on various media. Significant damages can be inflicted on both paintings and sculptures by the many pollutants in the atmosphere. The problem of nitric oxides in polluted atmospheres slowly degrading the surfaces of marble statues and marble buildings from ancient times is well known. In wood artifacts, acids can cause degradation of the cellulose structure present.

Paintings that are exposed to air and elements can become covered with foreign particles that change visual appearances and begin to act mechanically on the artifact. The paint itself as well as the substrate that has been painted on can begin to crack. There can be a loss of cohesion between paint layers on various media. Particles can flake off.

Among the greatest of our cultural treasures are Medieval wall paintings done in the fresco technique. They adorn many Medieval buildings, particularly in Italy. In the buon fresco method, pigments mixed with water were applied to freshly placed and still-wet lime mortar after initial carbonation, thus embedding the pigments well into mortar (or, more precisely, into the crystalline structure of the newly formed calcium carbonate). Paintings not only had marvelous color and visual qualities, they were quite stable as well. With time, however, salts can begin migrating through pore structures in the mortar due to dampness and other reasons, and salt crystallization can occur. The consequence is that severe degradation can occur in the form of flaking of paint layers or powdering of colors. Deeper damage can occur to the overall porous structures as well. Damaging salts or particulates can also come from wind-blown sources (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 32-33).

These and other sources and types of damage have long plagued curators and owners of these delicate frescoes. Many early attempts to conserve artworks ultimately did more damage than good. At one time, for example, varnishes were used over paintings in a misguided attempt to protect them. These now-darkened varnishes are a major problem in restoration efforts today. In more recent years, less problematic acrylic polymers such as ethyl methacrylate (paraloid) as well as others have been used to consolidate wall paintings. Even the best of current techniques, however, can still result in some type of change, not be very effective, or simply be short lived (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 35).

This technique has been widely used throughout the world and has led to the development of other sophisticated techniques as well.

Researchers at the Center for Colloid and Interface Science (CSGI) at the University of Florence have extended the Ferroni-Dini method using nanomaterial technologies. Calcium hydroxide would be especially desirable for conservation use with carbonate-based materials because of compatibility. A saturated calcium hydroxide water solution, known as lime water, has been used, but its low solubility has presented problems. The use of calcium hydroxide suspensions has been explored, but these are not stable enough and create surface effects. Researchers at the Center explored the use of dispersions of nanosized calcium hydroxide in nonaqueous solvents. Nanoparticles of this type can be obtained from a simple homogeneous phase reaction in hot water. Going to smaller sizes changed the physical and chemical features of the calcium hydroxide particles. Nanoparticle sizes ranged from 10 nm to 200 nm and were found to be able to penetrate within pore structures of wall paintings and limestone and without leaving surface effects (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 35-36).

The particles increased cohesion to the painted layers. After a short period of time, the calcium hydroxide particles were found to react with carbon dioxide in the air and create a greatly improved binder in the host material, thus consolidating it. The process essentially replaces calcium hydroxide lost during degradation. The same methods have been applied to many fresco paintings, including at the Maya archeological site of Calakmul. Interestingly, this consolidation method can be applied to other materials, including ancient brick mortar.

Using approaches similar to that just described, nanoparticles can also be used for conserving or restoring old textiles, paper, and wooden objects (see figure8).

Deacidification processes can be used to stabilize documents and increase the life of these papers, but these methods are expensive and slow. Nanoparticle-based paper treatments have been suggested for use to achieve more efficient and long-lasting deacidification.

Smaller particles allow easier penetration and more complete dispersion (see figure9). The approach generally suggests an improved way of dealing with one of our most delicate preservation problems.

The work on cellulose structures described previously has led to other applications. In the 17th century the royal battle galleon Vasa was built on the order of King Gustavus Adolphus of Sweden (see figure10). The ship was built of large oak, and its two gun decks held 64 bronze cannons. On its maiden voyage on August 10, 1628, the Vasa fired a farewell. A sudden squall caused it to list, and water poured through still open gun ports. The vessel capsized and sank with great loss of life. Amazingly, the ship's largely intact hull was salvaged in 1961. To prevent the hull from drying out, shrinking, and decaying, preservationists immediately treated it with polyetheylene glycol (PEG) by intermittent spraying and slow drying. It was moved to the Vasa Museum in Stockholm, where alarming rates of acidity increases in the wood were observed and again threatened the hull by acid wood hydrolysis. Sulfuric acids were proving especially harmful. The development of sulfurs was traced back to metabolic actions of bacteria in the harbor water and was subsequently oxidized by the iron released from longcorroded bolts as well as from more recent ones put in during salvaging. Preservation efforts focused on removing iron and sulfur compounds. Neutralization treatments using alkali solutions helped in only outer wood layers and can potentially cause cellulose degradation itself (Michael F. Ashby, Paulo Ferreira, Daniel

Schodek, 2009, 36-37).

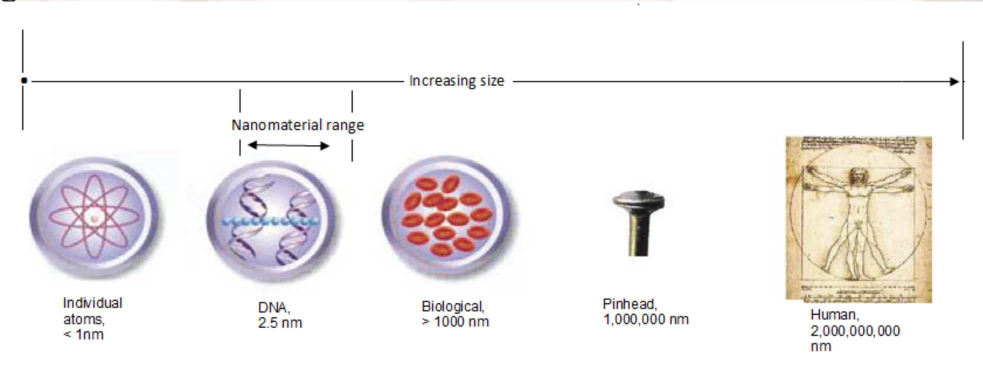
A new method of neutralizing the acids by the use of nanoparticles has recently been explored by the group from the University of Florence, mentioned previously. The immediate preservation focus was to slow the production of acids inside the wood and, if possible, remove the iron (or render it inactive) and sulfur.

Conclusion:

Work with nanotechnology has only recently been emerging in the conservation area, but initial results look very promising. For instance, the airborne pollutants from traffic or smog, which are known to attack the surface of sculptures and architectural monuments made of marble and other stones that form part of the cultural experience of our finest urban environments, might be combated with the self-cleaning. Indeed, the potential value of inert self-cleaning surface treatments would be literally enormous, but considerable gaps must still be bridged before we can safely benefit from these new nanotechnologies (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009,37-38).

In the last few decades, the conservation of cultural heritage has become a topic of interest worldwide, due to the need to preserve the authenticity of artifacts and constructions, as well as the history of mankind. Classic examples of artifacts include stone tools, wooden tools and objects, metal or personal ornaments and ceramic vessels. Due to the age of these objects and the external degradation factors, their structure is severely affected. For example, wood materials are constantly subject to several serious degradation factors, such as biological or chemical degradation, which more or less affect the structural integrity and mechanical strength of these materials.

Therefore, research scientists are still focusing their research to discover more appropriate new materials and their applications to conserve and restore human heritage items for future generations.



(Figure1) Sequence of images showing the various levels of scale (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 3).

(Figure2) Window from Chartres Cathedral. The intense colors of many Medieval stained-glass windows resulted from nanosized metal oxide particles added to the glass during the fusion process (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 30).

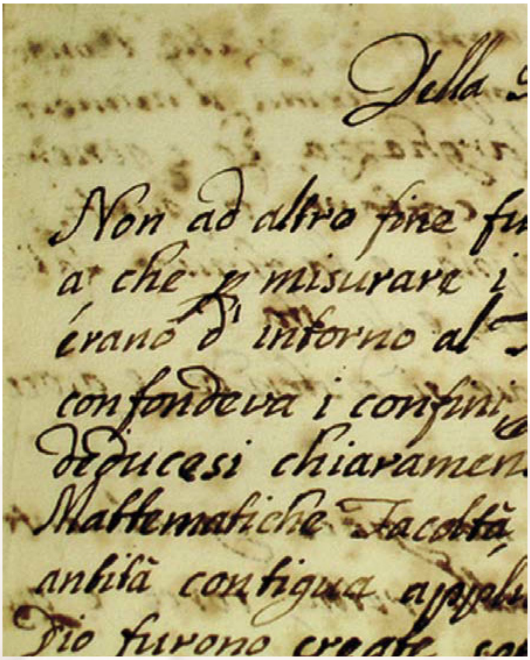
(Figure3) The Lycurgus cup looks green when light shines on it but red when a light shines inside it. The cup contains gold nanoparticles (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 31).

(Figure4) Medieval lusterware, circa 16th century, Manises, Spain. The glaze was made by firing metal oxides (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 22).

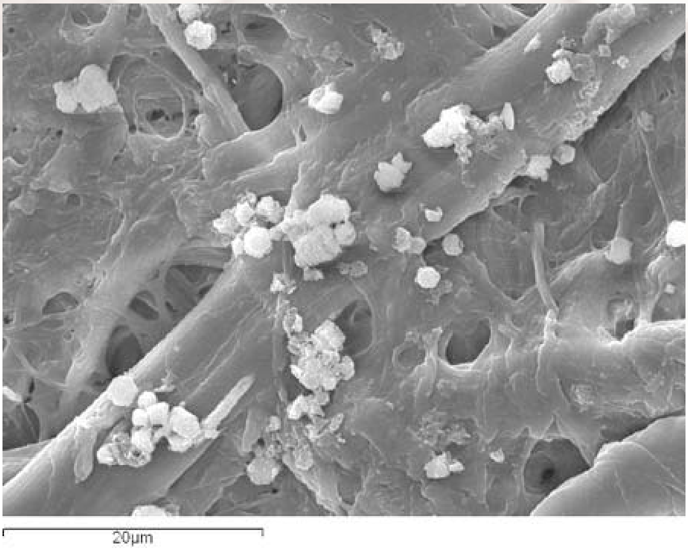
(Figure5) Mayan wall painting from Cacaxtla, Mexico. The intense blue results from an amorphous silicate substrate with embedded metal nanoparticles and oxide nanoparticles on the surface (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 32-33).

(Figure6) Conservation work was carried out in the 1970s using the Ferroni-Dini method for cleaning from sulfatation and consolidation of frescoes. Pre and post-restoration images under raking light (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 34).

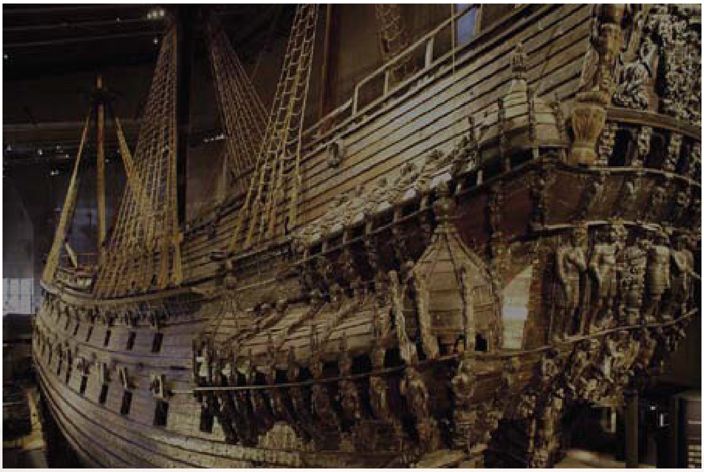
(Figure7) According to undocumented tradition, the face of the saint is a self-portrait of the artist, Beato Angelico. Pre- and post-restoration under glazing light (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 34).



(Figure8) Acid paper. (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 36).



(Figure9) Nanoparticles of calcium hydroxide on paper—deacidification (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 36).



(Figure10) The Vasa sank in 1628 and was salvaged in 1961. Originally treated with PEG, the hull was still threatened by acidification (Michael F. Ashby, Paulo Ferreira, Daniel Schodek, 2009, 37).

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