NANOTECHNOLOGY SUSTAINABLE CONSTRUCTION TOWARDS GREEN HERITAGE

Abstract

Nanotechnology is a very important diverse technological field that covers many applications especially building construction as it is a very promising sector which will lead to building more sustainable buildings because of the advantages of dealing with Nano-materials. This research focuses on how to link innovatively sustainable construction needs with Nano-technological opportunities when dealing with heritage buildings.

The research aims to demonstrate the role and importance of using Nanotechnology construction for greening heritage it also aims to provide a framework for addressing relevant issues of sustainable Nano-constructions, as a way to use it in reconstruction and revitalization of heritage buildings to achieve green heritage goals. This research raises a very important question "Is using nanomaterials in the reconstruction and revitalization of heritage buildings will be more sustainable and achieve the green heritage goals?" The research relay on extrapolation, analytical and descriptive methodology. The theoretical part will be dealing with Nanotechnology and its uses in the field of construction in general and the restoration of heritage buildings in particular. In its comparative analytical part, the research demonstrates characteristics of different international case studies for the purpose of using this technology in heritage buildings.

Conclusions will be drawn from the findings of this research on how to deal with this new sustainable Nano-constructions and how it could be applied on heritage buildings as a way for greening heritage buildings.

Key words

Nanotechnology, Sustainable Construction, Green Heritage Buildings

1. Introduction

Nanotechnology is a new technology which helps in improving energy efficiency, reducing greenhouse gas emission and deals with climate changes. Using nanomaterials in building construction have a very strong relationship with sustainability. Nanotechnology has a great impact on building construction materials properties which will help in improving building construction methods and wide use in architecture. Cultural heritage conservation is one which has many potentials that could help in greening heritage.

The methodology of this research focuses on how to link innovatively sustainable construction needs with Nano-technological opportunities. In its theoretical part many definitions related to nanotechnology and Nano architecture are explained, the classification of construction materials and nanotechnology is stated, and also it showed the relation between conservation of cultural heritage and nanotechnology. In its analytical part it showed many applications of using nanotechnology in heritage building construction and heritage conservation, the concept of sustainable heritage buildings, and some international case studies examples which focus on using Nano-materials in the conservation of heritage buildings. As it aims to demonstrate the role and importance of using Nano-materials in heritage building construction as a way for greening heritage and to provide

a framework for addressing relevant issues of sustainable Nano-constructions, as a way to use them in reconstruction and revitalization of heritage buildings to achieve green heritage goals.

2. Nanotechnology

2.1. Nanotechnology Definition

Nano" is a Greek word (Latin nanus) which means "dwarf". A nanometre is a millionth of a millimetre. (nm) is a millionth of a millimetre (1/1,000,000mm = 10-6mm) (Sylvia Leydecker, et al, 2008).

3. Nanoarchitecture

Nanoarchitecture is integrating nanotechnology in all architectural fields, through the use of Nano-materials, products, and shapes. It will help designers to develop their designing concepts, ideas, and thoughts…etc. (Cathryn Bang, 2011). It is also the conversion of architecture in new Nano revolution in the 21st century. (Al Samny, 2008).

4. Green Nano architecture and Nano-materials

4.1. Green Nanotechnology Definition

It means clean technologies development for reducing environmental potentials and risks of human health to replace any product with environmental friendly Nano products (Hemeida, 2010).

4.2. Green Nanotechnology and Sustainability

Sustainable architecture aims to reduce buildings negative impact on the environment as much as it can. It promises more sustainable production of goods, by using less energy and resources and using less toxic materials. (Hemeida, 2010).

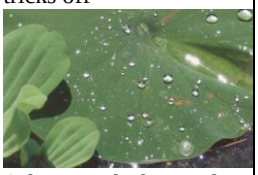
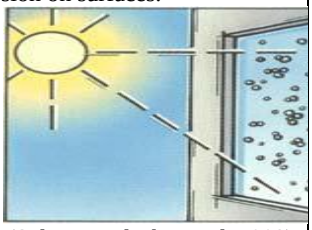
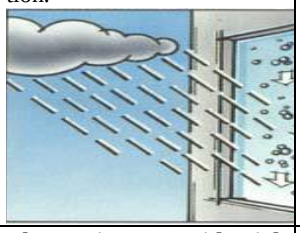
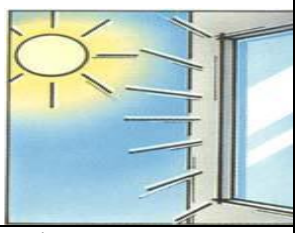
5. Nanotechnology and Sustainable Building Construction

Sustainability has a very strong relationship with Nano-materials uses in building construction. All fields of architecture (design, interior designs, …etc.) had achieved energy efficiency and more sustainable building construction through nanotechnology innovation. (Enrico Ercolani, 2016).

5.1. Nanotechnology and Indoor Nano-materials

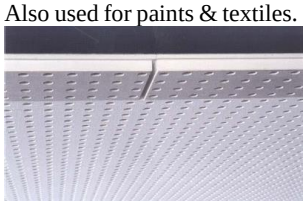
5.1.1. Coatings as an indoor Nano-material

Table 1: Coatings as an indoor Nano-material

Coatings				
Product	**Self-Cleaning: Lotus -Effect**	**Self-Cleaning: Photo catalysis**	**Easy-to-clean (ETC):**	**Antibacterial**
Properties	Hydrophobic – water tricks off  Sylvia Leydecker et al, 2008) pg. 58	Hydrophilic surfaces Deposited dirt is broken down and lies loosely on the surface	Hydrophobic i.e. water-repellent and often also oleo phobic Surface repellence without using the Lotus Effect.	Bacteria are targeted and destroyed.
Specifications	Microscopically rough, not smooth Well suited for surfaces that are regularly exposed to sufficient quantities of water.	A water film washes air away. UV light and water are required. Light transmissions for glazing and translucent membranes are improved.	Smooth surface with reduced surface attractions. Surfaces have a lower force of surface attraction due to a decrease in their surface energy.	The use of disinfectants can be reduced. Silver nanoparticles reduce the amount of cleaning time necessary.
Usage	It is used for optimal use to become much better and for (self-cleaning) facades. Minimize the requirement for cleaning	Reduce the extent of dirt adhesion on surfaces.  (Sylvia Leydecker et al, 2008)	Are found in interiors, but can be employed outdoors for better weather protection. 	Supports the methods of hygiene methods in healthcare areas. 
Example	**Museum of Ara Pacis, in Rome-Italy it was built in 2006.**   A white durable self-cleaning coating which had integrated invisibly in the building surfaces.	**Narita International Airport, Tokyo, Terminal 1. Chiba, Japan (2006)**  The building is protected against weather through membranes to improve passengers comfort. The membranes are coated with a self-cleaning photocatalytic coating, to minimize the cleaning cost.	**The private residential building, Erlenbach, Switzerland (2005)**   Protect wood against weather and slow its gradual grey discoloration.	**Patient's room prototype Berlin, Germany (2006)**  Good up-holstered fabrics are used. Because of using antibacterial and dirt-resistant properties of Nano silver particles the building remains clean. pleasant wood veneers are also used due to antibacterial varnishes.

5.1.2. Coatings (Environmental Materials)

Table 2: Coatings (Environmental Materials)

Coatings (Environmental Materials)				
	Air-purifying			
Product	Air-purifying Indoors	Air-purifying outdoors	Fire-proof	Scratchproof and abrasion-resistant
Properties	Decomposing doors chemically into harmless constituent parts.	Eradicate about 20 and 80% of airborne pollutants easily	A thickness of 3 mm of a functional fill material between glass panels is sufficient to provide more than 120 minutes of fire resistance of a temperature over 1000°C.	It can be applied to different materials such as wood, metal, and ceramics.
Specification	Cracking of molecules which gave carbon-dioxide and steam.	Photocatalytic concrete capacity gives combating pollutions,	Nanoparticles of pyrogenic silicic, are highly creative due to their large surface area.	Improve scratch-resistance with transparency.
Usage	Improve the quality of air and enables unpleasant odors and pollutants to be eradicated.	Purifying air	Protection against fire and high efficiency. Due to the formation of (Nano silicate) an opaque protective layer against fire & heat.	Scratchproof paints & varnishes protect varnished surfaces of parquet flooring (Leydecker, 2008). pg. 12
Applications	 The air-purifying curtain has antibacterial properties. Also used for paints & textiles.  Materials for purifying the air as plasterboard  Hyundai Motors Offenbach headquarters, Germany	  Air-purifying paving stones. (Ymanashii, 2004)  unvarnished wood and air-purifying building boards are used to eliminate airborne contaminants.	  Deutsche Post headquarters, Bonn, Germany Contra flam fire safety glass is used (Fahmy, 2010)	

5.1.3. Solar protection: Automatically darkens glass and vice versa.

Figure 1: Electro chromatic and Photo chromatic glass. source: Leydecker et al, 2008, pg. 144

5.1.4. Anti-graffiti: They are highly effective and are used to make building materials water-repellent and for reducing dirt.

Figure 2A: Noise barriers (anti-graffiti coatings) source: Leydecker et al, 2008, pg. 154

Figure 2B: Historic monuments "the Brandenburg Gate" in Berlin is protected with an anti-graffiti coating. Source: Sylvia Leydecker et al, 2008, pg 153

Figure 3: New Centre Ulm Ulm, Germany (2006) – These two buildings have a clean-cut form of concrete which is coated with a nanoscale high-tech coating. Source: Sylvia Leydecker et al, 2008

5.1.5. Anti-reflective: Improves solar transmission. It is a transparent nanoscale surface.

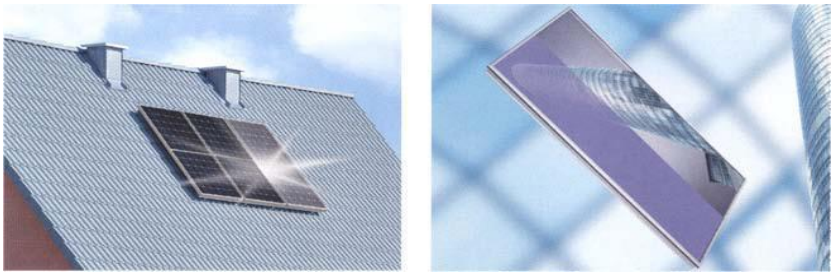


Figure 4: Reflected light that is reduced by using anti-reflective sheets. Source: Leydecker et al, 2008) pg. 159

5.1.6. Anti-fingerprint: It reduces the effect of the fingerprint.

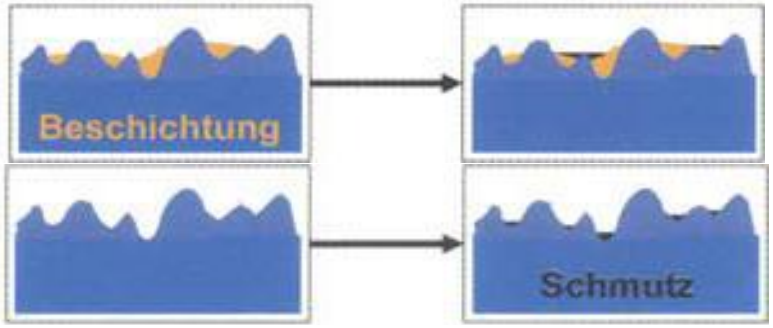
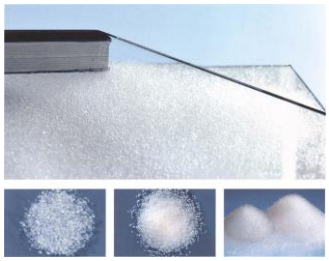
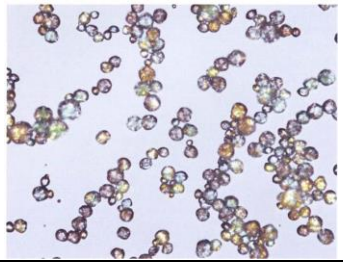
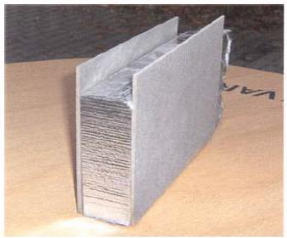
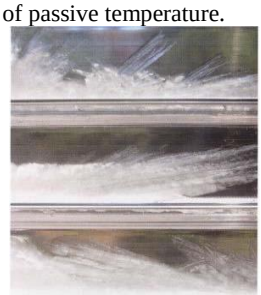
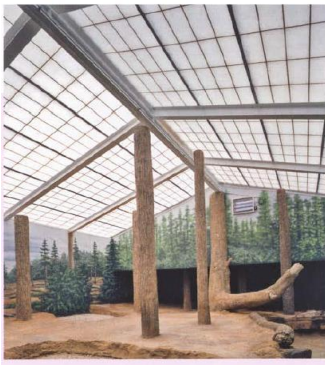


Figure 5: anti-fingerprint coating (up) and uncoated surface (down). Source: Leydecker et al, 2008) pg. 172

Table 3: Insulations as an Indoor Nano-material

Insulations			
Product	**Thermal Insulation: Vacuum insulation panels (VIPs)**	**Thermal Insulation: Aerogel**	**Temperature regulation: Phase change material (PCM)**
Properties	Thermal insulation is maximized & the thickness of it is minimized. 	Sound insulation with High-performance thermal insulation 	PCMs are composed of salt hydrates and paraffin. 
Specifications	The outer layer is made of stainless steel or plastic foil. The fill material takes the form of foam, powder or glass fibers. 	Light and airy Nano foam. Aerogel contributes towards energy efficiency. 	minimize heating and cooling. Regulations of passive temperature. 

Usage	Used both for new buildings constructions and in conversion and renovation work and can be applied to walls as well as floors.	Nano gel-filled glass panels are suitable for use in facades but also for interiors.	Conserving energy by reducing the energy demand for heating and cooling.
Applications	The center of Sonnenschiff in Freiburg, Germany (2006)   Insulations are used in the external walls.	Milwaukee County Zoo, WI. The USA it was built in 2005.  Aerogel-filled glass panels installation provides natural daylight which is glare-free with high energy efficiency.	Housing for elder people "Sur Falveng" Domat/Ems, Switzerland  The glass used in the building is a thick composite which is filled with salt hydrate material to help in storing heat and to protect spaces inside from overheating.

6. Nanotechnology and Classification of Construction Materials

Due to using nanotechnology in construction field concrete has become much stronger, very durable and placed more easily, steel is tougher and glass cleans itself. Its strength has increased and it became more durable to reduce the environmental footprint of the built environment (Surinder Mann, 2006). As shown in table 4.

Table 4: Nanotechnology Sustainable Construction Applications for Greening Heritage

Nanotechnology Sustainable Construction Applications			**It's Usage**	**Does Heritage Buildings Benefit from it**	**Benefits**
Construction Nanomaterials	**Concrete**	**Self-Compacting Concrete (SCC)**	Construction Elements (column, beam, slab…etc.) that could be rebuilt or repaired.	yes	It doesn't need vibration which helps in reducing the energy needed to build concrete structures and is a sustainability issue. SCC can offer benefits of up to 50% in labor costs.
		Fibber wrapping of concrete	Construction Elements (column, beam, slab…etc.) that could be rebuilt or repaired.	yes	Increase the strength of pre-existing concrete structural elements by closing small cracks on the concrete surface.
	Steel	**Stress Risers**	It helps in initiating cracks that result from the failure of fatigue.	Yes	It helps in the limitation of stress risers number, fatigue cracking which increases safety, minimize monitoring and more efficient.
		High strength steel cables	It is used in constructing bridges, and in tensioning of pre-cast concrete.	Yes	High strength and a stronger cable material would reduce the costs and period of construction
		Welds and Heat Affected Zone (HAZ)	(HAZ) are adjacent to welds.	Yes	Adding nanoparticles leads to increasing the toughness of welds. Which makes it a more sustainable and safe issue.
		Carbon Nanotubes (CNT's)	(CNT's) are strong and stiff materials with tremendous properties.	Yes	It is difficult to bind them and they pull out easily, rendering them ineffective, have a tensile strength, flexible and lighter as regarding their graphitic nature. Their thermal conductivity is high. They have great strength and low weight, also can be used as semiconductors and conductors.

		Nano flex and MMFX2	The two new products are corrosion resistant	Yes	They are corrosion resistant and have low cost.
	Wood		It contains nanotubes elements which are much stronger than steel.	Yes	Having Nano fibrils is a way to a new paradigm in green sustainable constructions.
	Stone		Find treatments for heritage conservation through enhancing the properties of materials.	Yes	Important advantages that could solve many problems found in the traditional interventions
	Glass	**Titanium dioxide (TiO2)**	It is used in coat glazing as it has sterilizing and anti-fouling properties.	Yes	TiO2 is hydrophilic and this attraction to water forms sheets out of raindrops which wash off the dirt particles. (Self-cleaning).
		Fire-protective	Fireproof	Yes	Fire resistant
		Thin film coatings	They are sensitive surface applications for window glass.	Yes	the potential to filter out unwanted infrared frequencies of light and reduce the heat gain in buildings.
		Thermochromics technologies	It reacts to temperature and provides thermal insulation.	yes	It gives heating protection whilst maintaining adequate lighting.
		Photochromic technologies	It reacts to changes in light intensity.	yes	It reacts to changes in light intensity by increasing absorption.
		Electrochromic coatings	Reacts to changes in applied voltage by using a tungsten oxide layer	yes	Reduces cooling energy and could make a dent in huge amounts used in the built environment.
In-door Nanomaterials	**Coatings**	**Self-Cleaning: Lotus -Effect**	Self-Cleaning	Yes	Cleaner appearance. Reduce maintenance demand.
		Self-Cleaning: Photo catalysis	Self-Cleaning and dirt's are easier to remove.	Yes	Reduce the extent of dirt adhesion & lead to savings in costs.
		Easy-to-clean (ETC):	Cleaning	yes	Stress-free and easy cleaning. It saves time and costs
		Antibacterial	Air purifying	yes	Purifies indoor air
		Air Purifying	Purifying air and break apart the pollutant molecules	Yes	Destroy air-borne pollutants.
		Fire Proof	A thickness of only 3 mm of a functional fill material between provides more than 120 minutes of fire resistance to flames of a temperature of over 1000°C.	Yes	Highly efficient fire protection. It is Light and transparent.
		Scratchproof and abrasion-resistant	It can be applied to different materials such as wood, metal, and ceramics.	Yes	Improve scratch-resistance with transparency. Protects varnished surfaces of gloss lacquered.
		Solar protection	It is a mean of integrating electrochromatic glass in buildings.	Yes	No blinds necessary. Glass darkens automatically (memory effect).
		Anti-graffiti	It makes building materials water-repellent	Yes	Highly hydrophobic and dirt-resistant.
		Anti-reflective	A single interference layer is applied by dipping the glass or plastic in the solution and functions across a broadband spectrum of light.	Yes	Improving solar transmission. Cost-effective and efficient anti-reflective solution.
		Anti-Fingerprint	The light reflections on the coating make steel or glass surfaces appear smooth, giving the impression of cleanliness.	Yes	No more visible fingerprints.
	Insulations	**Thermal: Vacuum insulation panels (VIPs)**	Used for new buildings constructions applied to walls as well as floors.	Yes	It can be useful in conversion and renovation work.
		Thermal: Aerogel	Nano gel-filled glass panels are used in facades & interiors.	Yes	Thermal insulator.
		Temperature regulation: Phase change material (PCM)	It reduces the energy demand for heating and cooling.	Yes	Conserving energy.

6.1. Conservation of Cultural Heritage and Nanotechnology:

Nowadays Nanotechnology had become the most important near future theoretical and applicative human knowledge framework, breakthroughs are restricted to few applications due to the importance of nanotechnology specially in the field of cultural heritage conservation. (Piero Baglioni, et al, 2011)

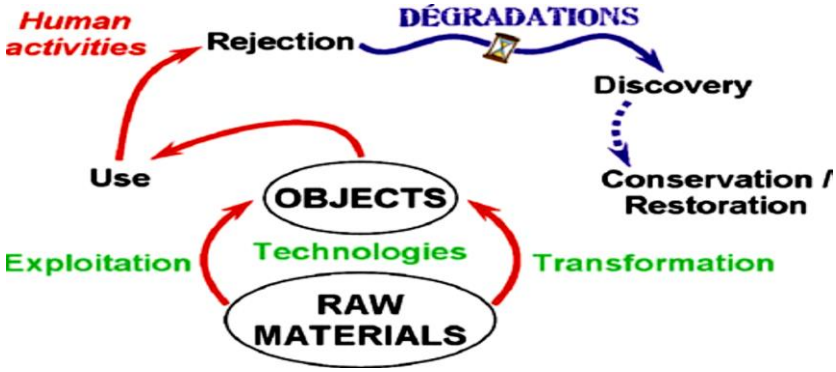


Figure 6: Illustration of the life cycle of Heritage objects.
Source: Philippe Dillmann, et al, 2016, pg. 208

Nanomaterials include important advantages that could solve many problems found in the traditional interventions. Nanotechnology has a great impact on heritage building construction that would help to improve the durability and performance of building construction materials, energy efficiency and safety of the monuments. The study of the effectiveness, durability and compatibility studies of new nanomaterials are very important to avoid using inadequate treatments, which affect and modify many properties of building materials. Also, the knowledge of the industrial production, the capacity utilization, and the price of raw materials are important aspects must be considered. Risks of human health and environmental implications as a result of using new nanomaterials shouldn't be forgotten.

7. Application of Nanotechnology in Building Construction and Heritage Conservation

In the last twenty years' nanotechnology developed and utilized rapidly. Nanotechnologies and nanomaterials have presently found their implementation in numerous areas of every day's life. (Navrátil 2008).

There are many innovative applications in construction such as Nano coatings with high resistance to microbial attack by moulds, bacteria, coatings protecting surfaces from many bad effects such as soaking, soiling, etc., or used as plate panels to increase fire resistance, or Nano plasters that protects building's façade from weathering effects, temperature fluctuations or solar radiation (Borovcová 2010).

7.1. Sustainable Heritage Buildings Concept

Sustainability is defined as a regard to heritage buildings through some main items as shown in figure 6 (Elborombaly, 2016).

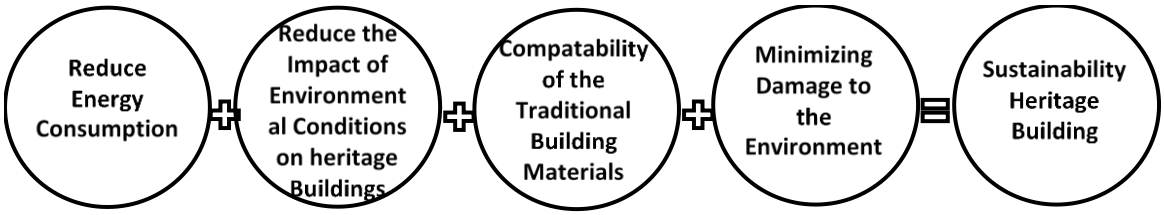


Figure 7: How can Sustainability Be Positive – Source: (Elborombaly, 2016) pg.6.

7.2. Technical Preservation for Heritage Buildings Materials: This concept is based on two preservation methods as shown in figure 7

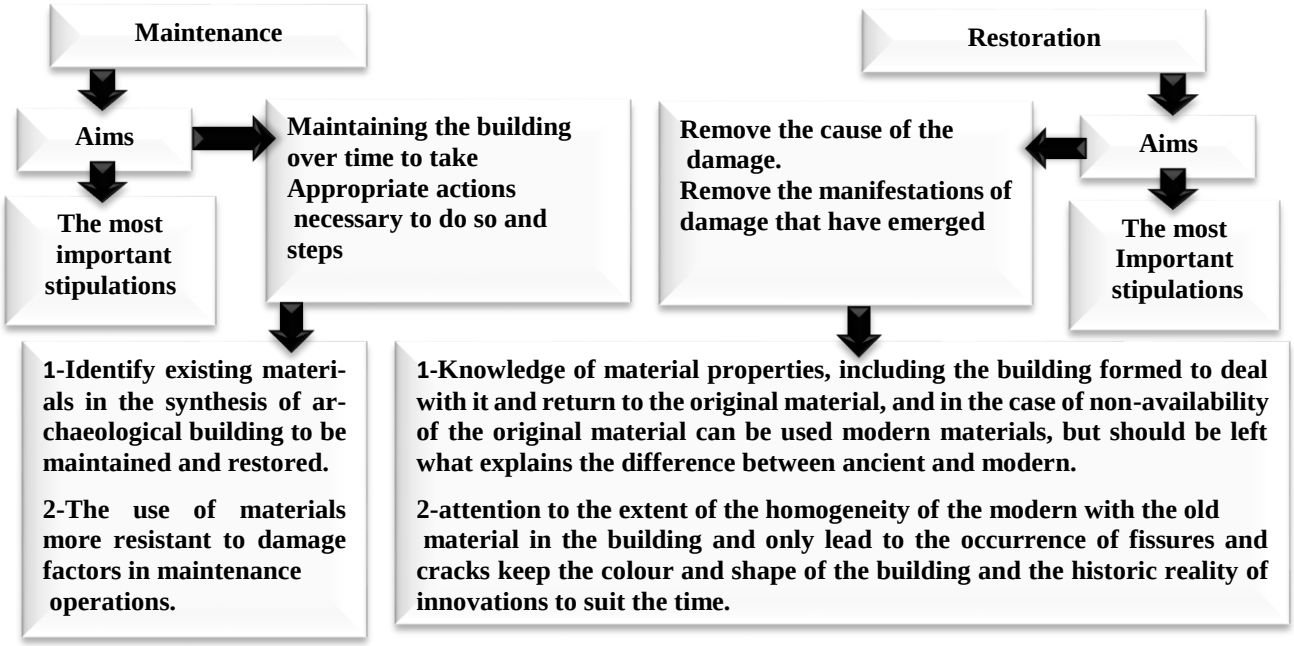


Figure 8: Technical Preservation for Heritage Buildings Materials. Source: (Elborombaly, 2016) pg.7.

Table 5: Using Nano-materials in the Conservation of Heritage Buildings International Examples

Nanomaterial used for restoration	Example	Problems facing the Building
Treatment of stone walls through using Nano silica.	**Monti Castle region of Puglia, Italy, 1240, AD**  A castle is a clear form of towers made of stones.	Wind and Groundwater damaged the walls.
Penetration of Nanomaterial inside the wall Strengthen calcareous stone walls and injects cracks textured calcium hydroxide in the nanoscale	**All Saints Church of England, Little Kimble**  It is built with lime stones and constructed windows north wall before the middle of the 13th century.	Moisture and salts. Cracks and separation between the layers of stone and gypsum. Presence of insects and dirt Kanako bat.
Formulations of alkaline-earth metal hydroxides nanoparticles dispersed in alcohol were applied to the stones.	**Univ. of Milan headquarters, Ca' Granda** 	Water freeze-thaw cycles and acid rain made degradation of stone detachment outermost layers.

8. Future Directions and Challenges for Greening Heritage

Fabrication: Nanotechnology fields focus on fabrication, characterization & the use of these materials. This leads to construction infrastructure development (Garcia-Luna, et, al, 2005)

8.1. Health:

Construction products might be harmful to health. (Tong, et, al, 2007).

8.2. Environment:

Nanomaterials has a great effect on the natural environment (NNI, 2003). All materials that are used in buildings construction and maintenance must be compatible with the natural environment and it should have a negative impact on the environment to reduce human health and environmental risks as construction infrastructure has provided in the natural environment.

8.3. Cost:

The costs of most Nano-materials and equipment are relatively high. (Mann, S. 2008.)

9. Conclusion and Recommendations

- Nanomaterials will produce buildings lighter, smaller and more robust which will save the cost of construction and saves a flat place for new generations.
- Nanotechnology innovation will improve buildings performance, energy efficiency, and sustainability which will help in greening heritage in heritage cities.
- Nanomaterials are about getting more function in less space. Efficiency and getting more with less is essential for sustainability as a way to greening heritage.
- Green Nanotechnology produces nanomaterials that don't have a negative impact on the natural environment and doesn't harm humans' health and produces Nano-products that provide innovative solutions to solve environmental problems.
- There are three main issues: Short vision, no skilled personnel, and Level of investment that might decrease and prevent the wide spreading use of nanotechnology and nano-materials in the reconstruction of heritage buildings.
- Nano-materials play an important role in the conservation of art, architectural objects, and heritage buildings.
- Useful innovative construction nanomaterials are going to help architects, civil engineers, and contractors to know the availability and advantages of using nanomaterials that would lead to innovative green, sustainable, and durable designs and structures.
- Properties of new materials need to be compatible with that of the historic materials so that new materials do not damage the historic ones.
- This is a call to material scientists: Several challenges are expected to happen in the next few decades. Although the nanomaterials developed so far are able to conserve the older legacies, new applications must be explored to safely preserve heritage buildings for future generations.
- Raising awareness of the importance of using nanomaterials in the reconstruction and revitalization of heritage buildings as it is the main gate to sustainability starting from undergraduate students to scientific research committees.
- Scientific research organizations should adopt more research projects in the field of nanotechnology for its important role in the restoration and reconstruction of heritage buildings as a way to greening heritage.
- There must be a production line for nanomaterials to reduce its high coast and therefore can be used more and more effectively when restoring and reconstructing heritage buildings.

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