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# EVOLUTION OF STUDIES ON BIOMIMETIC MATERIALS WITH APPLICATIONS IN REDUCING INFILTRATION BY ELETRODRAINAGE ON INFRASTRUCTURE WORKS

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**Abstract.** *This paper analyzes and compares various methods and materials for drainage and waterproofing of heritage building foundations at different deterioration stages due to water action. The study emphasizes the selection of drainage solutions based on comprehensive analysis of factors such as topography, slope, stratification, structural system, architecture, regional climate, and water flow characteristics. Recognizing the impact of these variables, the research highlights how identical drainage types can yield different results in distinct contexts. The durability of heritage structures, particularly those made of earth and brick, is heavily influenced by water-related deterioration, especially in high-rainfall regions. Recent intensification in research on surface water management, driven by climatic and morphological changes, underscores the importance of effective drainage and waterproof solutions. The study acknowledges the complexity of choosing optimal materials and systems from the diverse construction market and the significant resource consumption involved in such works. Hence, it advocates for the use of sustainable materials and resource-efficient methods. The proposed study focuses on innovative solutions for efficient drainage and waterproofing of heritage buildings, utilizing sustainable materials derived from waste or recycled sources. It emphasizes the adoption of electro drainage techniques alongside the application of silica nanoparticles to create superhydrophobic surfaces inspired by the lotus effect. These biomimetic surfaces, achieved through the modification of silica nanoparticles, offer superior water repellency and durability. Additionally, the study highlights the role of dimethicone as a key component in enhancing these properties. Electro drainage techniques are explored for their effectiveness in managing water infiltration and promoting efficient drainage in heritage structures. This method uses electrical fields to facilitate the movement of water away from building foundations, providing an eco-friendly and efficient alternative to traditional drainage methods. Silica nanoparticles are integral to the study, primarily for their role in creating superhydrophobic surfaces. These nanoparticles, when modified, mimic the micro- and nano-structural characteristics of lotus leaves, providing exceptional water repellency. The lotus effect, named after the self-cleaning properties of lotus leaves, is characterized by water droplets forming spherical shapes and rolling off surfaces, thereby carrying away dirt and contaminants. This effect is achieved by coating surfaces with silica nanoparticles, which create a rough nanostructure that traps small-scale air pockets, drastically reducing water adhesion. Dimethicone, a silicone-based polymer, is incorporated into the silica nanoparticle coatings to enhance their*

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*hydrophobic properties. This combination not only improves water resistance but also increases the overall durability and flexibility of the treated surfaces, making them more resilient to environmental factors. The study also compares the technical specifications and performance of calcium oxalate, a proposed material, with traditional materials used in drainage and waterproofing works. Calcium oxalate, known for its durability and environmental sustainability, demonstrates superior performance in maintaining the integrity of heritage buildings while minimizing the ecological impact.*

**Keywords:** Nanomaterials, Biomimetic Materials, Hydrophobicity, Silica Nanoparticles, Dimeticone, Lotus Effect, Electro Drainage, Heritage Building Preservation

## 1. Introduction

Nanomaterials are extremely small-scale structures, with dimensions on the order of nanometers (a nanometer is one billionth of a meter) [1]. They have caught the attention of researchers because of their unique properties, which differ significantly from those of macroscopic materials. The history of nanomaterials is relatively recent, but their development has had a profound impact in fields ranging from medicine to engineering and information technology.

The first steps in exploring the world of nanotechnology were taken in the 1950s and 1960s, when advanced microscopy techniques such as transmission electron microscopy (TEM) and scanning electron microscopy (SEM) allowed scientists to observe and manipulate structures at the atomic and molecular level [2]. However, the term "nanotechnology" was introduced by physicist Richard Feynman in his famous 1959 speech, "There's Plenty of Room at the Bottom", in which he discussed the possibility of manipulating materials atom by atom [3].

A milestone in the field of nanomaterials was the discovery of buckyballs, a form of nanostructured carbon, by researchers Harold Kroto, Robert Curl, and Richard Smalley in 1985 [4]. This discovery, which was awarded the Nobel Prize for Chemistry in 1996, paved the way for research into other forms of nanostructured carbon, such as the carbon nanotubes discovered in 1991 by Sumio Iijima [5].

The applications of nanomaterials are vast and diverse. In medicine, nanoparticles are used for targeted drug delivery, improved medical imaging, and the development of new therapies for diseases such as cancer [6]. For example, gold nanoparticles are used to improve the effectiveness of thermotherapy treatments, where the heat generated by nanoparticles helps destroy tumour cells with increased precision [7].

In the field of energy, nanomaterials contribute to the development of high-energy-density batteries and to increasing the efficiency of solar cells [8]. Carbon nanotubes, for example, are being used to improve the conductivity and strength of composite materials used in batteries [9].

Nanomaterials also have applications in electronics and sensors, where they are used to develop devices with reduced size and power consumption but superior performance [10]. One example is the use of silver nanoparticles in sensors for detecting gases and volatile organic compounds [11].

The impact of nanomaterials in technology and industry continues to grow as research reveals new ways to exploit their unique properties [12]. As technology advances and knowledge accumulates, nanomaterials are expected to play an even more central role in technological development [13].

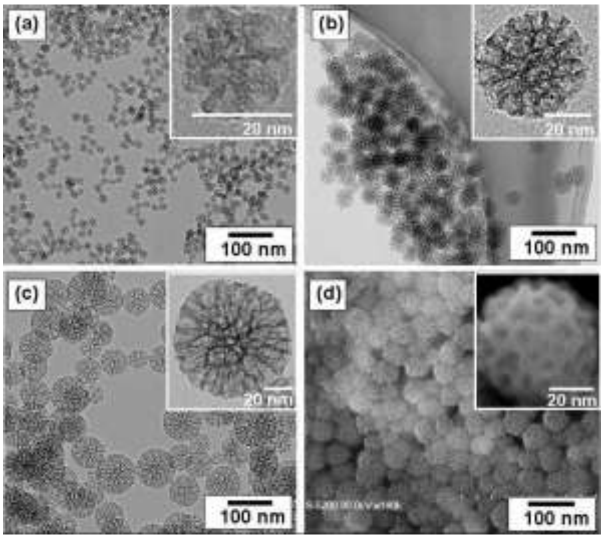


**Fig.1** Transmission electron microscope images (a, b and c) of meso-porous silica nanoparticles with diameters: (a) 20nm, (b) 45nm, and (c) 80nm. The scanning electron microscope image (d) corresponds to (b). From "Mathematics and Physics for Nanotechnology: Technical Tools and Modelling" Paolo Di Sia- University of Padova (Italy) & Primordial Dynamic Space Research (Verona - Italy)

An innovative perspective in the construction sector involves applying advanced technologies to modify surfaces and create innovative materials, extending research beyond the limits of silicon nanoparticles. Exploring a wide range of nanomaterials or specialized additives can revolutionize the properties of current building materials or lead to the development of new materials with superlative attributes. For example, integrating carbon nanotubes, metal nanoparticles, or other nanomaterials with exceptional thermal, mechanical, or insulating properties can strengthen concrete, insulation, and other structural components, improving their strength, durability, and energy efficiency [15]. Research may also be directed towards innovative coatings that offer self-healing or adaptation of their properties according to environmental conditions, paving the way for more durable, efficient, and sustainable buildings.

In recent years, advances in the synthesis and manipulation of silicon nanoparticles have opened new prospects for creating materials with unique characteristics. Among the many possibilities for the use of nanomaterials in construction, which offer a vast field for innovation and improved performance of modern buildings, one outstanding example is the exploration of the remarkable properties of silicon nanoparticles and their effect on surfaces, the discovery of their ability to induce hydrophobicity and create surfaces with enhanced roughness [18]. This discovery has encouraged the application of silicon nanoparticles in films developed for the prevention of ice formation, a leading field in aeronautics and functional materials [19].

In the context of building infrastructure, the introduction of biomimetic materials, including silicon nanoparticles and dimethicone, for surface hydrophobisation is a significant innovation. These materials are used to recreate nature-inspired effects such as the lotus effect, giving building surfaces superhydrophobic properties [21]. By creating a rough nanostructure that captures small-scale air pockets and using dimethicone to achieve low surface energy, improved moisture resistance and a significant reduction in infiltration can be achieved. This approach not only increases the durability and efficiency of buildings but also promotes greater sustainability by reducing the need for frequent maintenance and the use of environmentally harmful chemicals. Thus, the integration of these advanced materials in construction marks a significant step towards innovation and improved performance, aligning with current trends towards more resilient and sustainable buildings [24].

Previous studies have highlighted the potential of silicon nanoparticle-based coatings in reducing ice adhesion, thus providing a sustainable and energy-efficient solution to the problems associated with ice formation on aircraft. The development of methods such as spin casting and chemical vapor deposition has paved the way for the creation of superhydrophobic surfaces, essential in achieving successful icephobic coatings.

By optimizing the combination of silicon nanoparticles and fluoroalkyl silanes, the researchers sought to achieve durable, erosion-resistant coatings with improved performance under aeronautical conditions. In this context, the history of using silicon nanoparticles in the field of aircraft freeze prevention marks a continuing evolution of technologies aimed at making aviation safer and more energy efficient

Ice formation and build-up can hinder the economical and environmentally friendly operation of aircraft and pose a serious hazard that can cause accidents [29]. For aircraft, a de-icing and anti-icing system is required on the ground and during flight. However, current de-icing and anti-icing systems release chemicals into the environment, increase weight, increase fuel consumption, and add complexity to aircraft systems [30]. Aiming for an environmentally friendly and cost-effective solution to the problem of ice formation and build-up, a durable icephobic coating on the aircraft surface is potentially an ideal solution [31].

A surface with a water contact angle of 150° or greater, with very low resistance to flow, is considered super-hydrophobic [32]. Superhydrophobic surfaces are effective in allowing water droplets to bounce off, delaying ice formation and reducing adhesion to ice [33]. To fabricate superhydrophobic surfaces, both surface chemistry and morphology must be adjusted to achieve low surface energy and desired surface roughness [34]. Various methods have been developed to prepare a rough surface from a low surface energy material or to modify a rough surface with a low surface energy material, such as electrochemistry, mechanical processing, chemical etching, spin casting, and chemical vapour deposition [35]. Among them, a combination of centrifugal casting of a rough material and chemical vapour deposition of a low surface energy material is simple and cheap [36].

Coatings incorporating silicon nanoparticles have attracted significant interest due to their high thermal and mechanical stability and high surface roughness. Among low surface energy materials, fluoroalkyl silanes are promising for practical applications due to their high mechanical and chemical stability resulting from strong siloxane bonding. In previous research, hydrophobic silicon-based coatings have been widely reported. However, the icephobicity, freezing behavior, and durability of silicon nanoparticle-based coatings have been less investigated [40]. In addition, the durability of hydrophobic/icephobic coatings is very important for practical applications and has remained a challenge. An erosion testing method based on the impact of water droplets released from an upper floor using gravity has been reported [42]. In this experiment, an erosion testing device measuring the impact of water droplets at various velocities and angles on the material was installed and used to assess durability.

The current work proposes the use of silicon nanoparticles to create the lotus effect and the formation of a hydrophobic perfect layer. This feature will be achieved by various methods, to form a rough nanostructured surface to trap small-scale air pockets on the surface of silicon nanoparticles. The chemical vapor deposition method will be used to achieve low surface energy Hydrophobicity, icephobicity, and durability of the coatings will also be examined [46].

The fabrication of silicon-based nano coatings with self-assembled monolayers for the aerospace industry may offer the possibility of developing a high-performance material to obtain a surface with hydrophobic properties used in the construction industry

Nanomaterials are a cornerstone of technological evolution and innovation in the construction industry, offering advanced solutions to today's challenges. These microscopic materials, thanks to their exceptional properties, offer remarkable advantages over conventional materials, changing traditional construction paradigms.

The use of nanomaterials in the construction industry has generated numerous benefits due to their superior properties such as reduced size, improved strength, and specific functionalities that respond to contemporary needs for sustainability and energy efficiency. Nanomaterials are being integrated into various building materials, from cement to paints and insulation, fundamentally changing the way buildings are designed and constructed [2, 5-7].

Nanomaterials are often added to cement to improve their mechanical properties and durability. Additives based on nano-SiO2, for example, are used to fill intermolecular spaces in cement, resulting in a denser and stronger material. This leads to an increase in the durability and compressive strength of concrete, which is essential for long service life constructions. Materials such as carbon nanotubes are also being integrated to develop concrete with self-healing properties that can repair cracks without external intervention.

Nanotechnology applied in windows, known as smart windows, uses nanostructures to regulate heat transfer and light, helping to reduce energy consumption in buildings. These windows can change their optical properties according to external stimuli, reducing the need for artificial lighting and air conditioning. Insulating materials such as aerogels also use nanostructures to provide superior insulation, making them particularly useful in the thermal renovation of old buildings [10-13].

Integrating nanotechnology into construction processes has the potential to reduce the carbon footprint of building materials by using less raw material and increasing the durability of structures. Nanoparticles, such as nano-silica and nano-titanium, are being used to improve the durability of concrete, thereby reducing waste from early material failure.

Nanomaterials help improve the properties of building materials, including fire resistance, water resistance, and corrosion protection. Nanocellulose, for example, is being used to develop highly fire-resistant building materials, providing extra time for evacuation and firefighting.

In summary, nanomaterials are transforming the construction industry, offering advanced solutions that address contemporary challenges related to sustainability, energy efficiency, and environmental impact. They are essential for the development of future construction projects that not only meet today's technical requirements but also contribute to a more sustainable future [19, 20].

An illustrative example of the revolutionary potential of nanomaterials is the use of silicon nanoparticles to produce superhydrophobic surfaces. These surfaces, inspired by the structure of the lotus leaf, repel water and other liquids, facilitating self-cleaning and protecting exposed surfaces from degradation. Researchers such as Olga Lyapidevskaya, Junpeng Liu, Zaid A. Janjua, Martin Roe, Fang Xu, Barbara Turnbull, Kwing-So Choi, and Xianghui Hou have shown how silicon nanoparticles, modified with self-assembled monolayers, can create superhydrophobic and super oleophobic surfaces. These technologies have broad applications, including in the protection of exterior building structures and in improving the efficiency of solar panels by preventing the accumulation of dirt or water [21-25].

Also, Muhammad Salman Saleem from the City College of the City University of New York demonstrated the innovative capabilities of superhydrophobic surfaces obtained using silicon nanoparticles, highlighting their importance in architectural design and building materials. Other researchers, such as Xinde Tang, Xiuying Hu, Haichuan Jia, Xiaoman Sun, and Hongtao Ling, explored the use of silicon nanoparticles in the fabrication of superhydrophobic transparent surfaces, opening new horizons for applications in windows and other glazed surfaces [26-30].

Wang X., Li X., Lei Q., Wu Y., and Li W. advanced research by combining fluorosilicon resins and silicon nanoparticles to develop a superhydrophobic composite material. This material has valuable applications in protecting the exterior surfaces of buildings from water and dirt, highlighting the versatility and effectiveness of nanomaterials in construction [31-33].

The effective implementation of municipal waste management and the adoption of sustainable practices are particularly relevant in the context of the negative impact of human activities on the environment. The construction industry, being a significant consumer of natural resources and energy, plays an important role in this dynamic, having a profound environmental, social, and economic impact on communities.

In this context, the development and use of innovative materials, such as nanomaterial-enriched concrete, becomes crucial. Concrete, a mixture of natural aggregates, cement, and water, is fundamental in construction because of its availability and efficiency. However, the environmental impact of cement production is significant, releasing around 480 kg of CO2 for every cubic meter of concrete produced. This has stimulated research into greener alternatives, such as the use of micro silica and other recycled materials, to reduce the consumption of cement and natural aggregates.

Micro silicon, a by-product of ferrosilicon production, contains over 85% SiO2 and has a spherical particle shape with a specific surface area between 13,000 and

23,000 $m^2/kg$. Its use in construction not only improves the properties of concrete but also contributes to reducing the environmental impact of the sector [39, 40].

In addition to micro silicon, dimethicone and silicon nanoparticles are two other examples of nanomaterials with transformative potential in construction. Dimethicone, a silicone-based polymer, can be used to improve the strength and durability of materials, while silicon nanoparticles offer an effective solution for creating superhydrophobic surfaces that mimic the lotus effect and promote natural biomimicry. These technologies not only improve the performance and efficiency of building materials but also help reduce environmental impact by promoting durability and minimizing the need for maintenance.

In conclusion, nanomaterials open new horizons in the construction industry, offering innovative solutions to sustainability and efficiency challenges. Their use in developing new materials and improving existing ones promises a revolution in construction, marking the beginning of a new era of innovation and sustainability.

Nanomaterials have thus become a crucial element in technological innovation and development in the construction industry, offering revolutionary solutions to contemporary challenges. These materials, due to their microscopic size and unique properties, offer significant advantages over traditional materials.

**Use of Nanomaterials in Construction**

Nanomaterials are a cornerstone of technological evolution and innovation in the construction industry, offering advanced solutions to today's challenges. These microscopic materials, thanks to their exceptional properties, offer remarkable advantages over conventional materials, changing traditional construction paradigms [1-4].

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Nanomaterials have thus become a crucial element in technological innovation and development in the construction industry, offering revolutionary solutions to contemporary challenges. These materials, due to their microscopic size and unique properties, offer significant advantages over traditional materials.

The lotus effect, named after the similar property of the lotus plant (Nelumbo nucifera), is a fascinating breakthrough in biology and materials technology. This natural phenomenon has inspired many innovations in engineering and design due to its remarkable self-cleaning properties. The following details the main aspects of the lotus effect, how it occurs, why it exists, the structure of the surface it acts on, and its composition.

The lotus effect is the result of a specific combination of microscopic structure and chemical composition of lotus leaf surfaces. Essentially, this effect manifests itself in the leaf's ability to repel water and dirt particles. When water droplets hit the leaf surface, they pick up dust and dirt particles and simply slide or bounce off the leaf, leaving behind a clean surface. This process is made possible by the micro- and nano-structural characteristics of the leaf [32, 33].

The structure of lotus leaves that allows this effect is made up of very small epidermal papillae, which are coated with wax. These papillae are conical structures with rounded tips, densely arranged on the leaf surface. Each papilla is coated with wax nanoparticles that increase the hydrophobicity of the surface. These small structures increase the roughness of the leaf's surface, which helps minimize contact between water and the leaf's surface.

The wax that coats the papillae has complex compositions, including various types of organic compounds such as long-chain alcohols and fatty acids. These compounds are hydrophobic, repelling water and contributing to the repulsive effect observed.

The self-cleaning mechanism of lotus leaves is due to the combination of the microscopic structure and chemical composition of the leaf. When a water droplet hits this surface, the adhesion force between the water and wax is less than the tension between the water molecules. As a result, the water cannot 'break apart' to fill the microscopic spaces between the papillae, remaining instead in a spherical shape that rolls easily off the leaf.

The lotus effect is an evolutionary adaptation that helps lotus plants stay clean, even in watery or muddy environments where dirt might inhibit the efficiency of photosynthesis. By keeping the leaves clean, the plant can photosynthesize more efficiently and absorb sunlight without hindrance.

The lotus effect is essentially a perfect example of how nature can inspire technological innovation to help people build a cleaner and more efficient future. So, inspired by the lotus effect, researchers have developed a variety of 'superhydrophobic' materials and surfaces that mimic these properties. These technologies are being applied in areas as diverse as creating paints and coatings that repel dirt and water, roofing materials that don't require frequent cleaning, and even in display technology that stays clean and clear in wet conditions.

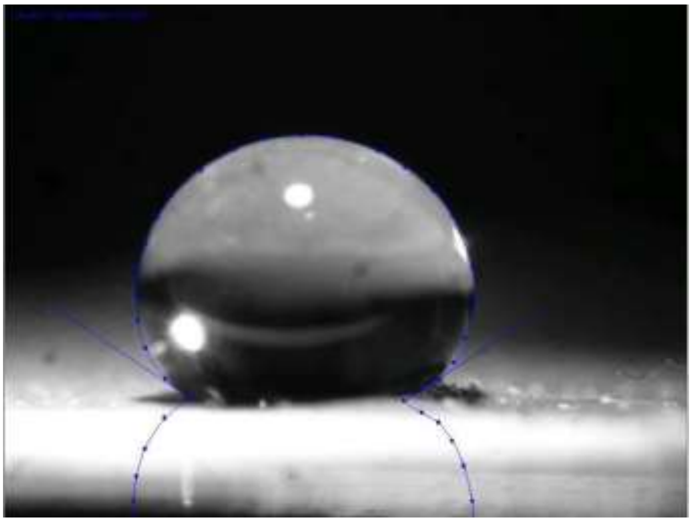

**Fig.2** A drop of water on the surface of a lotus shows contact angles of about 147°.
(https://en.wikipedia.org/wiki/Lotus_effect)

### 1.1. Lotus Effect in Hydrophobic Materials

The lotus effect, or superhydrophobicity, is a phenomenon observed in lotus leaves (Nelumbo nucifera), which have the remarkable ability to stay clean and dry, even in wet and dirty environments. This effect is due to the unique properties of the leaf surface, which allow it to repel water and dirt particles. By exploring the details of this effect, we can discover how biomimicry is inspiring new technologies and materials. The surface of lotus leaves is covered with epidermal papillae, rough microstructures that are in turn coated with nanoscopic wax. These papillae are conical and arranged in a dense pattern, creating a dual roughness at both the micro and nano levels. The waxes covering these papillae are composed of a range of hydrophobic compounds, including long-chain alcohols, fatty acids and paraffinic compounds. These compounds are essential in creating and maintaining the hydrophobicity of the leaf surface. When a drop of water touches the surface of a lotus leaf, a large contact angle (usually greater than 150 degrees) is formed. This large contact angle causes the water droplets to take on a spherical shape rather than flattening out. Due to the high surface tension, water cannot spread over the surface of the leaf and instead slides off the leaf easily, taking any dirt or particles with it. The self-cleaning effect is a direct result of the hydrophobic properties and structure of the lotus leaf. Because water cannot adhere to the surface, it picks up dirt particles as the droplets roll off the leaf, leaving behind a clean surface. Lotus leaves are renowned for their ability to stay clean because the water that falls on them forms

droplets that roll over the surface, taking dirt with them. This is thanks to a micro-nano structure that creates a highly hydrophobic surface. This principle has been applied in the development of paints and coatings that prevent fouling and corrosion in architecture and vehicles. The production and research of silicon nanoparticles is a highly relevant area in nanotechnology. Their discovery and development have had a significant impact in many fields, including electronics, pharmaceuticals and the study of advanced materials. The following is a history of the evolution of the use of these nanoparticles in technology, from how they were discovered to the present day.

### 2.2. Silicon nanoparticles and polydimethylsiloxane

In the search for sustainable solutions for the protection and maintenance of infrastructures, research has focused on exploring the exceptional properties of biomimetic materials. One outstanding example of this is silicon nanoparticles, which offer the potential to mimic the hydrophobic behaviour of lotus leaves. This plant, known for its natural ability to repel water and dirt, has inspired the development of superhydrophobic surfaces that mimic its micro- and nanostructure. Silicon nanoparticles, through their modifications at the molecular level, can create similar effects, generating a large contact angle between the surface of the material and water droplets. This phenomenon not only prevents water from adhering to, but also facilitates self-cleaning, vital characteristics for improving waterproofing in foundations and other structural elements of buildings. Therefore, the study and application of silicon nanoparticles as hydrophobic materials is a step forward in making water management in construction more efficient, while promoting principles of sustainability and durability in architectural and engineering design. Biomimicry is a fascinating interdisciplinary field that explores how biological solutions to environmental, anatomical or behavioral problems of living organisms can be emulated or inspired to develop technological innovations. This approach is based on the idea that nature, through billions of years of evolution, has already optimised a few highly efficient processes and structures.

## 3. DETERMINATION OF HYDROPHOBIC CAPACITY AND CREATION OF LOTUS EFFECT ON PROPOSED SURFACES

### 3.1. Materials proposed for research

Within the research on the materials traditionally used in building foundations, special emphasis is placed on heritage buildings, where foundation techniques must respect the structural and aesthetic integrity of these historic buildings. Two fundamental types of materials used in these foundations are stone and burnt brick, each with specific characteristics that influence application methods and structural performance.

Stone is a traditional material used in foundation construction because of its durability and natural strength. In heritage buildings, the use of stone is often preferred to preserve architectural authenticity. The simplest and most common method, involves creating a continuous foundation beneath the entire structure, using large, heavy stones to support the weight of the building. Mortar is used to fill the gaps between the stones, which increases the cohesion and stability of the structure. A more complex technique used to distribute loads from overlying structures. Foundation beams are made of precisely cut stones assembled to form a solid base for the walls.

Burnt brick, another traditional material, is valued for its mechanical strength and durability properties and is frequently used in foundations for smaller buildings or as part of repairs.

In the case of brick masonry foundations, beams are often made of the same bricks, assembled in a way that effectively distributes loads from walls and other structural elements.

These materials include burnt brick, natural stone and various types of binders. This selection reflects the conventional and diversified substrates used in foundation systems, providing a sound basis for assessing performance and compatibility with modern preservation technologies. Their choice was motivated by their strength and durability qualities, fundamental in the context of new construction and rehabilitation, providing a robust foundation currently used in practice for the application of advanced compositions such as mortar or innovative solutions based on silicon nanoparticles. The mortar used in the experiment will be a traditional cement-based mortar, but with a significant innovation: the incorporation of silicon nanoparticles, averaging 20-30 nm in size. These nanoparticles have been dispersed in the mortar to significantly improve its properties.

A distinct innovation is the dispersion of silicon nanoparticles in dimethicone, a type of silicone polymer with emollient properties, which serves as a dispersing medium for the nanoparticles. This approach not only ensures a uniform distribution of nanoparticles in the mixture, but also contributes to improving the physical and

chemical properties of the final material, optimising adhesion, flexibility and resistance to environmental factors. The use of dimethicone as a vehicle for the silicon nanoparticles adds an additional advantage, giving the finished composition outstanding hydrophobic properties and improved resistance to wear and external degradation factors. This advanced methodology opens up new possibilities for their application in diverse fields, this study examining them as novel biomimetic materials in heritage restorations of foundation systems in construction, promoting improved performance as superhydrophobic materials.

The analysis and reformulation of the application of this advanced material focuses on the conservation and restoration of heritage buildings, with special attention to infrastructures made of stone masonry or burnt brick. The integration of silicon nanoparticles in building materials, especially in mortar, proposes a significant step towards the realisation of a lotus effect biomimicry, which induces remarkable hydrophobic properties in treated surfaces. This lotus effect not only increases the resistance of materials to weathering and external degradation factors, but also provides self-cleaning, thus contributing to the long-term preservation of historic structures.

The application of this type of advanced technological solutions in the field of restoration and conservation of cultural heritage is an innovative approach, allowing the authenticity of the materials to be maintained while significantly improving their performance. The hydrophobicisation effect induced by silicon nanoparticles provides protection against water penetration and other damaging agents, extending the life of structures and maintaining the aesthetic integrity of heritage buildings. Thus, the incorporation of nanoparticle technology in the preservation of architectural infrastructure opens new horizons for protecting and extending the life of historic buildings, adapting them to meet the challenges of the modern environment.

## 4. Sample preparation

### 4.1. Preparation of modified silicon nanoparticles

For the preparation of a homogeneous solution in which silicon nanoparticles are dispersed in dimethicone (polydimethylsiloxane) by a process involving mechanical mixing and subsequent thermal stabilisation. Dimethicone, a silicone-based polymer, serves as an ideal medium for the incorporation of silicon nanoparticles due to its chemical compatibility and physical properties. By combining these two materials, we obtain a composition that mimics the hydrophobic characteristics of lotus leaves, notable for their ability to repel water and dirt. The study of combining silicon nanoparticles with dimethicone is motivated by the search for effective solutions to improve waterproofing, especially in critical applications such as building foundations. The superhydrophobic properties of this combination can prevent water penetration into the underlying structures, reducing the risk of structural damage and prolonging the durability of buildings. Silicon nanoparticles are produced by methods such as flame pyrolysis or the sol-gel technique. Pyrolysis involves vaporising silicon in a flame at high temperatures, where nanoscale particles are formed by rapid cooling. The sol-gel technique involves the transition from a solution to a solid gel, in which the silicon polymerises to form fine particles. Predominantly composed of silicon dioxide ($SiO_2$), silicon nanoparticles have an amorphous structure, providing high specific surface area and excellent chemical stability. Dimethicone is synthesised by polymerisation of chlorosilanes in the presence of water, forming a polysiloxane network. The process includes hydrolysis and condensation of silane monomers, followed by polymerisation to obtain various molecular weights, depending on the application. Dimethicone is a polymer formed from repeating siloxane units ($[-Si(CH_3)_2-O-]_n$), where methyl groups are attached to silicon atoms, giving it hydrophobic properties and high thermal stability. Combining silicon nanoparticles with dimethicone creates materials with superhydrophobic, lotus leaf-like properties, essential for applications such as waterproofing foundations. These materials not only improve the water resistance and durability of structures, but also reduce the need for frequent maintenance, contributing to more sustainable and resource-efficient construction. Continued research in this area is vital for the development of new technologies to meet the challenges in construction and beyond. A systematic and innovative approach is essential. Given the need to achieve uniform dispersion of silicon nanoparticles in a non-aqueous medium such as dimethicone, here is a detailed proposal for the preparation process: Pre-dispersion of silicon nanoparticles: Pre- disperse the silicon nanoparticles in a dimethicone compatible solvent, which can be a short chain alcohol or another non-aqueous organic solvent, to facilitate subsequent mixing with dimethicone. Concentrations of 10, 20 and 30 grams of silicon nanoparticles per 100 g of solvent are used to explore different loading ratios.

## Conclusions

Analyzing the information presented and considering the reference studies in literature, it can be concluded that the development and application of solutions based on dimethicone enriched with silicon nanoparticles represents a promising approach in the field of advanced materials for the protection and preservation of building infrastructure. Based on the references studied, the following possible outcomes and benefits are identified: Biomimicry and lotus effect.

The lotus effect refers to the exceptional ability of lotus leaves to stay clean, even in dirty environmental conditions, due to their superhydrophobic properties. The surface of the leaves is covered with tiny papillae that minimize contact with water and dirt particles, allowing water to glide off easily, taking any impurities with it. The reproduction of the lotus effect in building materials using a combination of silicon nanoparticles dispersed in dimethicone is a promising innovation in materials technology. This mixture can impart superhydrophobic properties to building surfaces, mimicking the way lotus leaves repel water and dirt.

Integrating this type of technology into building protection solutions could have multiple benefits, including:

Improved water and dirt resistance: Treated surfaces would repel water and dirt effectively, keeping buildings clean for longer periods.

Extended durability: Treated materials could better withstand degradation factors such as erosion, mould and fungal growth due to improved protective barriers.

Reduced use of water and cleaning chemicals: The self-cleaning properties of surfaces would reduce the need for water and detergents, contributing to environmental sustainability.

Improved waterproofing efficiency: According to Lyapidevskaya and collaborators at the Federal University of Technology, Akure, Nigeria, advanced waterproofing materials offer significant protection to underground structures. Integrating silicon nanoparticles into solutions such as dimethicone could extend this protection, creating effective barriers against water penetration.

Superhydrophobic properties: Studies by Liu et al., Saleem of CUNY City College, and Tanga et al. highlight the ability of silicon nanoparticles to generate superhydrophobic surfaces when appropriately modified. Application of these nanoparticles in combination with dimethicone on building substrates promises to create a film with superior water and dirt resistance, helping to self-clean and maintain the exterior cleanliness of buildings.

Durability and strength: References by Wang et al. and Basu & Kumar highlight the potential of combinations of fluorosilicone resins and silicon nanoparticles in the fabrication of superhydrophobic composites. By extrapolation, the use of dimethicone as a base for dispersing silicon nanoparticles could improve the durability and strength of mortar and other building materials, protecting against erosion, fungi and other degradation factors.

Versatile applications: In the context of the studies mentioned, the diversity of manufacturing methodologies and potential applications indicates the versatility of these materials. Their implementation in the field of heritage conservation, for example, offers a compatible and effective solution for the protection of historic structures without compromising the aesthetic appearance or integrity of the original material.

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[38] xxx - ISO/TS 80004-1:2015 - Nanotechnologies. Vocabulary. Part 1: Core Concepts This international standard defines core terms related to nanotechnologies that are essential for the correct understanding and application of nanoparticles in various fields, including construction.
[39] xxx - ASTM E2456-06(2012) - Standard Terminology Relating to Nanotechnology This provides the standard terminology used in nanotechnology and is crucial to ensure clear communication and common understanding in the field of nanoparticle use.
[40] xxx - ISO/TS 80004-4:2011 - Nanotechnologies. Vocabulary. Part 4: Nanoparticles This standard specifies terms and definitions related to nanoparticles, which are fundamental to their application in construction and building materials.

*For specific building- regulations, the following standards have been considered:*

[41] 50. xxx - EN 197-1:2011 - Cement - Part 1: Composition, specifications and conformity criteria for common cements - This standard is crucial for understanding the composition and properties of cement used in nanoparticle mortars.
[42] 51. xxx - ISO 13007-1:2004 - Adhesive materials for ceramic tiles - Definitions, specifications and test methods - This international standard defines specifications and test methods for adhesives, including those modified with nanoparticles.
[43] 52. xxx - ASTM C1585-13 - Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes - This standard provides a method for testing the rate of water absorption in hydraulic cement-based concretes, relevant to the evaluation of nanoparticle mortar performance.