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The Impact of Nanoparticles Implementation on Conservation of Heritage Buildings (Overview the Nanocathedral Project)

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Abstract:

There is no doubt that heritage buildings play an important role in any country in the world, where they transport the civilization and architecture of the past to present and future, set the design basis, and transfer knowledge of previous architects to us so that we start from where they ended. Problems are how they constitute also one of the main reasons to know cultures of different peoples and their ways of diverse social lives. During the search for different ways and multiple techniques to preserve heritage buildings in order to extend their life span, it was founded that sustainability can be input to the traditional building materials so as to make them able to meet the challenge of the current and anticipated future conditions. This can be done by modern technology, which was permitted by the global and international organizations to use in those buildings, as rule (10) of Venice Charter states the use of the latest technical, scientific and construction methods after confirming their validity for the monument. This Paper is directed towards overview the study of modern technology, which all developed countries seek, which is the Nano technology that has become the main driver of all different sciences and technologies. Dealing with the concept of preserving, the heritage buildings, and different methods of preservation. Each of these phases consists of several techniques and chemical substances that can be divided into dry and wet techniques. This Deals with the study of some of the chemical substances used in the technical preservation operations in terms of sustainability.

Europe possesses remarkable cultural and environmental diversity, as well as an extraordinary wealth of ancient architecture and constructed surroundings. However, this architectural magnificence and historical legacy can give rise to deterioration issues due to the diverse range of stone materials employed in their construction. In this project, a selection was made of five distinct medieval cathedrals and a contemporary opera theater. These structures were chosen because they can be viewed as representative examples of diverse environmental conditions and various types of stones (such as limestones, sandstones, and marbles) prevalent in Western Europe. The primary objective of the project was to develop novel materials, technologies, and procedures for restoring and conserving stone in ancient cathedrals and monumental edifices. The emphasis was placed on preserving the originality of the building materials while also devising customized approaches to address specific preservation challenges. Thorough analyses and classifications were conducted on the original materials, examining their historical links to quarry exploitation as a source of construction resources. Nanomaterials suitable for consolidating and safeguarding stones were developed with the aim of providing optimal technological solutions for preserving different stone types, taking into account factors such as porosity, mineralogical composition, and chemical characteristic.

Keywords: heritage building -Political Problems-Nano Architecture-Nanoparticles

الملخص:

لا شك أن المباني التراثية تلعب دورًا مهمًا في أي دولة في العالم ، حيث تنقل حضارة وعمارة الماضي إلى الحاضر والمستقبل ، وتضع أسس التصميم ، وتنقل إلينا معرفة المعماريين السابقين حتى نتمكن من نبدأ من حيث انتهوا. المشاكل هي كيف أنها تشكل أيضًا أحد الأسباب الرئيسية لمعرفة ثقافات الشعوب المختلفة وطرقها المتنوعة في الحياة الاجتماعية. أثناء البحث عن طرق مختلفة وتقنيات متعددة للحفاظ على المباني التراثية من أجل إطالة عمرها الافتراضي ، تم تأسيس أن الاستدامة يمكن أن تكون مدخلاً في مواد البناء التقليدية لجعلها قادرة على مواجهة التحدي الحالي وتوقع مستقبل. الظروف. يمكن القيام بذلك عن طريق التكنولوجيا الحديثة التي سمحت المنظمات العالمية والدولية باستخدامها في تلك المباني ، حيث تنص القاعدة (10) من ميثاق البندقية على استخدام أحدث الأساليب الفنية والعلمية والبناء بعد التأكد من صلاحيتها للنصب التذكاري. . هذا البحث موجه نحو لمحة عامة عن دراسة التكنولوجيا الحديثة التي تسعى إليها جميع الدول المتقدمة ، وهي تقنية النانو التي أصبحت المحرك الرئيسي لجميع العلوم والتقنيات المختلفة. التعامل مع مفهوم المحافظة والمباني التراثية وطرق الحفظ المختلفة. تتكون كل مرحلة من هذه المراحل من عدة تقنيات ومواد كيميائية يمكن تقسيمها إلى تقنيات جافة ورطبة. يتناول هذا دراسة بعض المواد الكيميائية المستخدمة في عمليات الحفظ الفنية من حيث الاستدامة.

تتمتع أوروبا بتنوع ثقافي وبيئي كبير جنبًا إلى جنب مع الهندسة المعمارية القديمة والبيئة المبنية. من وجهة نظر الحفظ ، قد يؤدي هذا التميز المعماري والتراث إلى مشاكل تدهور تتعلق بمجموعة متنوعة من المواد الحجرية المستخدمة في بنائها. في المشروع ، تم اختيار خمس كاتدرائيات مختلفة من العصور الوسطى ومسرح أوبرا معاصر حيث يمكن اعتبارها ممثلة للظروف البيئية المختلفة وأنواع الأحجار (الحجر الجيري والحجر الرملي والرخام) في أوروبا الغربية. يهدف المشروع إلى تطوير مواد وتقنيات وإجراءات جديدة لترميم وحفظ الحجر في الكاتدرائيات القديمة والمباني الأثرية ، مع التركيز بشكل خاص على الحفاظ على أصالة مواد البناء وعلى تطوير نهج مخصص للتعامل مع المشاكل المحددة. تم تحليل

المواد الأصلية وتصنيفها وتقييم ارتباطها بالاستغلال التاريخي للمحاجر كمصدر لمواد البناء. تم تطوير المواد النانوية المناسبة لتوحيد وحماية الأحجار بهدف توفير أفضل إجابة تكنولوجية للحفاظ على أنواع مختلفة من الأحجار ، وفقًا للمسامية والخصائص المعدنية والكيميائية.

Introduction

Preserving Cultural Heritage is crucial for humanity to uphold the history of mankind and safeguard the authenticity of artifacts and architectural structures. One of the primary challenges related to the preservation of outdoor monuments is their constant exposure to weathering agents, which gradually deteriorate the surfaces and structures. Stone materials, in particular, experience various types of alteration and degradation as they age, influenced by the chemical and physical properties of the stone itself and the specific macro- and microclimatic conditions of the outdoor environment. In addition to these factors, the location of buildings within an urban setting and human activities play significant roles in the decay process. It is essential to consider these factors as variables that are intertwined with the historical development of local communities throughout the centuries, as well as the more recent industrialization and deindustrialization of city centers. The Research aims to raise the awareness of the effect of using nanotechnologies and nanoparticles in Heritage Buildings to elevate the efficiency of preserving Monumental and Heritage Buildings.

Research Significance

Nanotechnology has become in the forefront of the most important fields and has given a great expectation for future scientific revolution which will change the technology in many applications particularly the science of conservation and maintenance of heritage buildings. The recent developments in the materials science has shown that many of the problems facing the heritage buildings can be solved effectively with interference of chemistry, physics and other sciences.

Research Problem

1. As stated by EL-Essawy M.A. (2012), the architectural and urban heritage faces numerous challenges that have a negative impact on both its physical and visual aspects. Ultimately, these challenges can result in the destruction and loss of valuable heritage, whether in the short or long term. Consequently, it becomes crucial to identify these problems and their root causes as a fundamental approach to effectively address and preserve heritage. These problems can be categorized into the following elements:
2. Problems related to the human factor.
3. Environmental problems.
4. Economic problems.
5. Political problems.
6. Organizational and technical problems.

The traditional techniques and materials used in conservation and maintenance of heritage buildings had no significant effect in preventing the building from perishing, microbial infection, not being well isolated or protected enough or water saturation in same elements in the building.

Discussion

In recent years, the preservation of cultural heritage has gained significant global importance as artifacts and monuments face ongoing threats of degradation. Consequently, finding suitable consolidators that can effectively preserve and maintain the authentic appearance of these objects becomes crucial. The purpose of this study, as outlined by The National Organization for Civilization Coordination (2010), is to present an up-to-date overview of the primary nanomaterials utilized in the conservation and restoration of cultural heritage.

- A heritage building can be defined as a structure or establishment that possesses historical, symbolic, artistic, architectural, urban, or social significance. According to The National Organization for Civilization Coordination (2010), there is a consensus that buildings designated as heritage facilities or possessing a distinguished architectural style should exhibit the following characteristics:
- Community acceptance: To gain acceptance and positive interaction from society, which allows it to continue. ·
- A cultural and social phenomenon: to be an expression of material, moral or intellectual phenomena in a specific period of time. ·
- Resilience and continuity: that is, its condition allows for its continued existence and the possibility of dealing with it.

Types of Heritage Buildings:

1. Buildings and structures of distinguished architectural style: It is the buildings and facilities combined or individual or gardens that are distinguished by their value technical, building materials, or construction methods used and apply to them. The following standards and specifications (The National Organization for Civilization Coordination, 2010):
   A. It was built according to concepts or an architectural school
   B. Reflect the features of a particular historical era
   C. A spontaneous architecture that expresses a local environment
   D. Characterized by scarcity and uniqueness

2. Buildings and structures associated with national history: They are the buildings that were associated with influential and decisive national events

in the history of Egypt (The National Organization for Civilization Coordination, 2010).

3. Buildings and structures associated with a historical figure: They are the buildings that were associated with an Egyptian or non-Egyptian personality that had an impact, obviously, whatever its field in the march of society. And the character's connection to the building or origin as a result of birth, upbringing, continuous residence, work, or architectural design of the building or facility (The National Organization for Civilization Coordination, 2010).

4. Buildings and facilities that are considered a tourist attraction: They are the buildings and facilities that the general public used to visit for the purpose of tourism (The National Organization for Civilization Coordination, 2010).

Problems facing Heritage Buildings

The architectural and urban heritage is exposed to many problems that affect it negatively, whether on the physical, visual level or both together, and ultimately lead to the destruction and loss of this heritage. These problems can be classified into the following elements (EL-Essawy M.A., 2012):

1. Problems related to the human factor:

Problems related to the human factor	**Results**
1. Misuse and carelessness with heritage buildings	Destruction and damage to the interior elements of buildings
2. Neglecting the periodic maintenance necessary to maintain on heritage buildings as a result of the low economic level	The harmful effect on the structure of buildings and facades over time or the continuation of harmful malfunctions in buildings, such as drainage malfunctions and so on
3. Taking care of heritage buildings as separate units from urban surroundings.	The negative impact on the integrated visual image and change The character of
	the building as part of the surrounding urbanization is lost
4. Lack of use of some buildings	Stopping the maintenance work and exposure to negligence and infringements with the time

5. Infringement of architectural style by interfering with deletion or modify some parts	Changing the character of the building with modifications and additions, both on horizontal, vertical, or both
6. Carrying out unplanned maintenance work, such as redoing finishing the facades in unthoughtful ways that are technically approved.	Distortion and blurring of the effect and its distinctive architectural character
7. Not following international scientific requirements while maintaining and restoring processes.	Unintentional negligence resulting in damage to the trace or parts from it.

2. Environmental problems:

Environmental problems	**Results**
1. Groundwater level fluctuation	Affects the foundations of buildings and leads to uneven subsidence equal to each other and represents a great danger to them.
	Water leakage and leaching through the walls as a result of the level rise underground water
2. Emergency natural phenomena such as earthquakes or floods or hurricanes.......etc	Total or partial destruction of heritage buildings because they were not designed to bear these factors
3. Lack of resistance to some materials used in the building for gases, atrean, fungi and bacteria.......etc.	Damage to these parts of the building in a way that threatens the integrity of the building when exacerbated.
4. The sequence of expansion and contraction processes resulting from constant changes in temperature.	Cracks that may increase with time threaten the safety of the building

3. Economic problems:

Economic problems	Results
1. The high value of lands in cities, especially the downtown areas.	Encouraging encroachments on archaeological heritage buildings by demolishing them And destruction, which is often concentrated in these areas.
2. Lack of funding sources required for projects to upgrade heritage areas, both urban and architectural.	The inability to continuously follow up on the necessary maintenance and repair work for these buildings.
3. Insufficiency of government capabilities to upgrade these areas due to the lack of sufficient budgets and to consider this as a non-necessity, especially in developing countries.	The required government neglect of these buildings and areas and the lack of adequate government supervision necessary to protect them.
4. The lack of alternative housing units or adequate financial compensation in the desire to empty these areas.	Exacerbating the housing problem and threatening these areas with the continued emergence of slums and so on.

4. Political problems:

Political problems	Results
1. Absence of laws and legislation necessary to preserve archaeological buildings, especially with regard to the surrounding architecture.	Helped to encroach on archaeological buildings, due to the weakness of the penalty applied in cases of encroachment, demolition, or intentional damage, which makes it non-deterrent, in addition to not being applied in many cases, so that these encroachments turn into a fait accompli that cannot be removed.
2. The law dealt with the archaeological building with the same provisions it deals with the artistic monument, despite the difference in the nature of each of them and the environment surrounding it.	
3. The absence of legislation regulating the role of municipalities in the maintenance of archaeological and valuable buildings and the	

protection of the surrounding environment.	
4. The lack of laws and regulations for regulating construction works within the historical heritage areas.	The rise of modern buildings inside archaeological areas, thus damaging the foundations and walls of old heritage buildings, distorting the visual image and changing the formation of the heritage environment itself.

5. Organizational and technical problems:

Organizational and technical problems	**Results**
1. Some state agencies rent archaeological and historical buildings.	Not considering and paying attention to the quality of these jobs that may not be compatible with the building and damage it.
2. The lack of qualified and trained technical staff capable of implementing or following up the implementation of projects to preserve heritage areas.	Carrying out maintenance and restoration work without experience, which exposes these areas and buildings to damage and damage.
3. The absence of technical bodies and institutes specialized in graduating architectural restoration workers.	Reliance on archaeological restorers, despite the difference in the nature of the building as an antiquity when restoring it from paintings, tiles, statues and other artifacts.
4. Allowing the entry of motor vehicles of various types and sizes (buses / cars / motorcycles) to historical areas and the severe damage they cause.	These areas were established before the invention of the automobile, and transportation at that time was by buggy or buggy-drawn carts, and therefore the street widths and paths were in a manner commensurate with the size and speed of movement, but with the spread of cars and the change in the social composition of these areas, the issue of entering the vehicle into these areas became one of the most prominent problems Due to the damage it causes to historical buildings, whether due to vibrations or due to sulfur gases resulting from exhaust.

The definition of nano:

- The term "nano" originates from the Greek word for dwarf and is employed as a prefix denoting a unit of measurement. For instance, a nanometer (nm) is equivalent to one billionth of a meter or 10-9 meter (Waked A. M., 2011).
- Defining nanotechnology can be challenging, which led to the establishment of a committee known as the National Nanotechnology Initiative. This committee outlined the following defining features of nanotechnology (Waked A. M., 2011):
- - Nanotechnology encompasses research and technological advancements within the range of 1 nanometer to 100 nanometers.
- - Nanotechnology involves the creation and utilization of structures that exhibit unique properties due to their small size.
- - Nanotechnology capitalizes on the ability to control and manipulate matter at the atomic scale, and it involves the development of materials or devices within this size range.

Nanoarchitecture definition

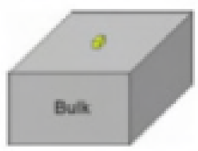
- Nanoarchitecture refers to the adaptation of architecture to the emerging nano revolution in the 21st century. The application of nanotechnology in architecture encompasses a wide range of aspects, including materials, equipment, forms, and design theories (Waked A. M., 2011).

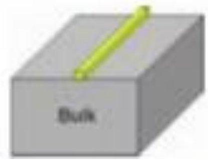
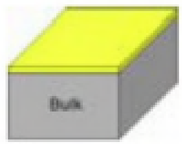
Nanoparticles

- The integration of nanoparticles or other nanomaterials into traditional materials aims to enhance the properties of the original material while also introducing new functional characteristics or even enabling multifunctionality (Waked A. M., 2011).

Nanomaterials

A nanomaterial is an object that possesses at least one dimension within the nanometer scale. Examples of commonly encountered nanomaterials include nanotubes, dendrimers, quantum dots, and fullerenes (Waked A. M., 2011).

Nanomaterial Dimension	**Nanomaterial Type**	**Example**
All three dimensions < 100nm	Nanoparticles, Quantum dots, nanoshells, nanorings, microcapsules	

Two dimensions < 100nm	Nanotubes, fibres, nanowires	
One dimension < 100nm	Thin Films, layers, coatings	

Classification of nanomaterials:

A. The classification of nanomaterials typically involves two main categories: fullerenes and inorganic nanoparticles (Waked A. M., 2011).

B. Fullerenes are a group of carbon allotropes that can be visualized as graphene sheets rolled into tubes or spheres. Carbon nanotubes and silicon nanotubes are examples of fullerenes (Waked A. M., 2011).

C. Inorganic nanoparticles, which consist of metals, semiconductors, or oxides, are particularly noteworthy due to their diverse properties such as mechanical, electrical, magnetic, optical, and chemical characteristics. Nanoparticles serve as a significant subject of scientific exploration as they bridge the gap between bulk materials and atomic or molecular structures. While bulk materials typically possess consistent physical properties regardless of their size, this is often not the case at the nanoscale (Waked A. M., 2011).

Nano material products:

According to Waked A. M. (2011), there are various material products that benefit from nanotechnology, such as coatings, insulation, air purifiers, and solar protection. One of the objectives is to impart self-healing capabilities through a process called "self-assembly." Nanotechnology is applied to paint and insulation, where nano-sized cells, pores, and particles are added, creating limited paths for thermal conduction. As a result, these coatings have high insulation values, with R-values double those of insulating foam. Currently, this type of paint is utilized for corrosion protection under insulation due to its hydrophobic nature, which repels water and safeguards metal from saltwater damage.

Furthermore, TiO2 nanoparticles possess remarkable properties and are being utilized as a coating material on roadways in experimental trials worldwide. These TiO2 coatings have a photo-catalytic effect, capturing and decomposing both organic and inorganic air pollutants. For instance, a coating of 7,000 square meters of road in Milan led to a 60% reduction in nitrous oxide levels, showcasing the potential of this technology. Additionally, self-cleaning coatings mentioned earlier, designed for glazing, take advantage of TiO2 nanoparticles.

Self-cleaning: Lotus-Effect

- Microscopically rough, not smooth.
- Hydrophobic - water trickles off.

The self-cleaning mechanism known as the Lotus-Effect is achieved by designing surfaces that are microscopically rough rather than smooth. These rough surfaces exhibit hydrophobic properties, causing water to trickle off them. The Lotus-Effect is a well-known approach for creating surfaces using nanomaterials. The term itself evokes images of water droplets forming beads on the surface. However, it is important to note that the Lotus-Effect should not be confused with surfaces labeled as "easy-to-clean" or with photo-catalysis, which is another self-cleaning mechanism (Waked A. M., 2011).

Self-cleaning: photo-catalysis

- Hydrophilic surfaces.
- Deposited dirt is broken down and lies loose on the surface.
- A water film washes dirt away.
- UV light and water are required.
- Reduces maintenance requirement

One of the main advantages of the Lotus-Effect is its ability to significantly reduce the adhesion of dirt on surfaces. This self-cleaning mechanism, particularly in photo-catalytic applications, provides a low-maintenance and hassle-free solution. Another benefit is the improvement in light transmission for glazing and translucent membranes, as the presence of surface dirt and grime is minimized. This reduction in surface contaminants allows for better daylight penetration, leading to potential energy savings by reducing the need for artificial lighting (Waked A. M., 2011).

Easy-to-clean (ETC)

- Smooth surfaces with reduced surface attraction.
- Surface repellence without using the Lotus-Effect.

Easy-to-clean (ETC) surfaces are often mistaken for other self-cleaning mechanisms like the Lotus-Effect. However, unlike the Lotus-Effect, ETC surfaces are smooth rather than rough. These surfaces possess water repellency and are characterized by a lower surface energy, which reduces surface adhesion. As a result, water is repelled, forming droplets that easily roll off the surface. ETC surfaces exhibit hydrophobic properties and often have oleophobic properties as well, repelling both water and oils (Waked A. M., 2011).

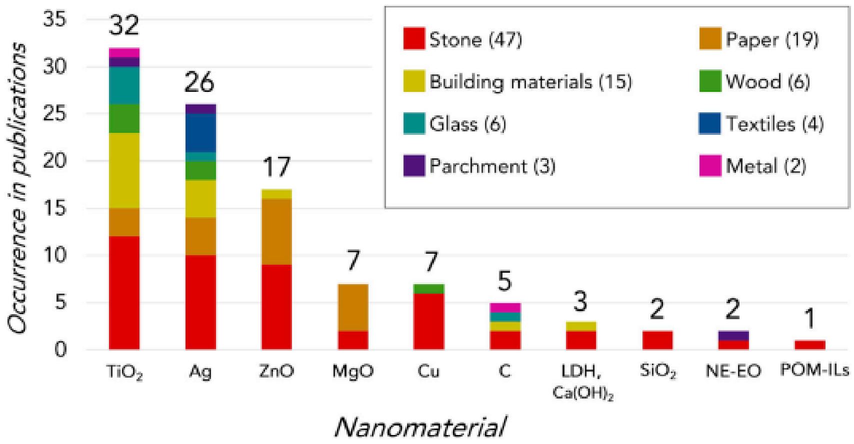
Antimicrobial Agents in Cultural Heritage Conservation

Antimicrobial nanoparticles:

In accordance with Franco-Castillo et al. (2021), the antimicrobial properties of certain materials, such as silver, zinc oxide, or copper, have been recognized since ancient times. Historical examples include the Egyptians storing water in copper or silver containers to ensure its drinkability, and the use of silver coins during the exploration of the Wild West to preserve milk freshness and prevent the growth of algae and bacteria in drinking water. Zinc oxide (ZnO) has also been used since 2000 BC for treating boils and injuries. The antimicrobial efficacy of these materials is further enhanced when their particle size is reduced to the nanoscale. This is attributed to fundamental changes in the electron properties within the crystalline solid, as well as improved interactions with cells and intercellular components like proteins, DNA, and ion channels. Nanomaterials have been extensively studied for their antimicrobial properties in various applications, including water disinfection, food packaging, and healthcare. Consequently, it is not surprising that nanomaterials have emerged as antimicrobial coatings and treatments in the field of heritage conservation over the past decade.

In the field of heritage science, nanomaterials have found extensive use in processes such as deacidification, consolidation, and cleaning. Several commercial products are already available for these purposes. However, the detailed investigation of these applications is beyond the scope of the mentioned review by Franco-Castillo et al. (2021).

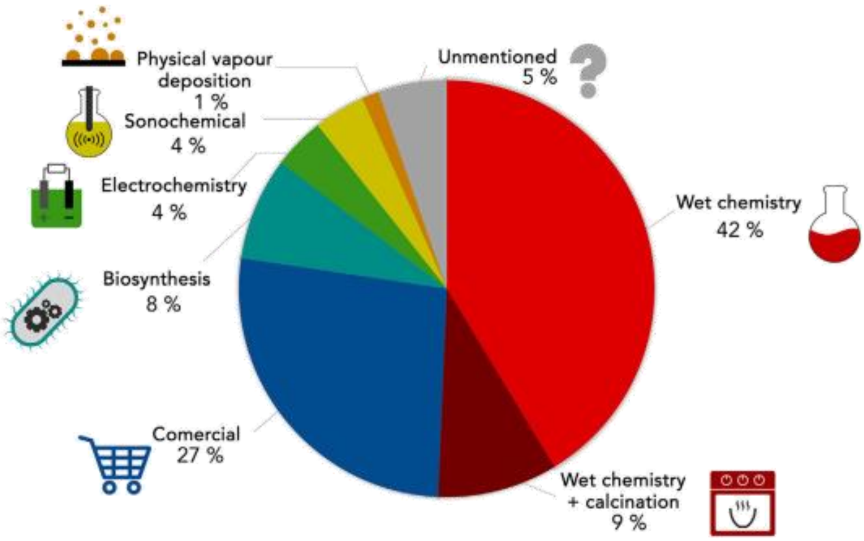
According to Franco-Castillo et al. (2021), titanium dioxide (TiO2), silver (Ag), and zinc oxide (ZnO) nanoparticles (NPs) are the most commonly used nanomaterials for preventing or treating microbial colonization of heritage substrate materials, in that order. Other frequently reported nanomaterials include silicon dioxide (SiO2), copper (Cu), magnesium oxide (MgO), zinc derivatives such as calcium zinc hydroxide dihydrate (Ca[Zn(OH)3]2.2H2O), carbon nanomaterials (graphene, graphene oxide, and fullerene), and layered double hydroxides (LDH).



Frequency of studies of a nanomaterial for each type of heritage item substrate

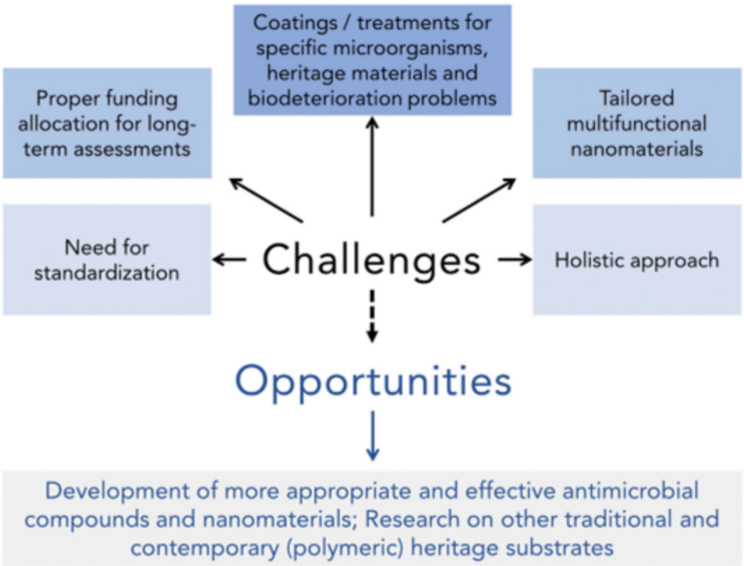
Nanomaterials	**Properties**
TiO_2	UV protection, hydrophobicity, self-cleaning, fire resistance, protection against microorganisms, dimensional stability
ZnO	UV protection, resistance to fire and scratches, hydrophobicity, protection against microorganisms, dimensional stability
Au	Anti-microbial, anti-fungal, anti-biofilm
Ag	Protection against microorganisms
MgO	UV protection, hydrophobicity, protection against microorganisms
FeO	UV protection, protection against microorganisms
SiO_2	Fire resistance, self-cleaning, hydrophobicity, scratch resistance
CuO	Protection against microorganisms
HAp/Au	Anti-aging protection, mechanical resistance, hydrophobicity

In accordance with David et al. (2020), certain synthesis methods for nanomaterials have involved a calcination treatment (9%) to produce oxides like TiO2, MgO, or ZnO. Commercial materials have also been widely used in the field (up to 27% of the published literature), with TiO2, ZnO, and AgNPs being the most commonly utilized commercial nanomaterials. The availability of these three materials from commercial suppliers has contributed to their extensive study as antimicrobial agents in the field of heritage conservation.



Origin of the antimicrobial nanomaterials used in heritage conservation

Challenges and opportunities in heritage conservation science



Challenges and opportunities in heritage conservation science

Nano Cathedral Project:

The Nano-Cathedral project, initiated in 2015 as part of the EC Horizon 2020 framework, involved collaborative efforts between European research centers, companies specializing in engineered inorganic nanoparticles, conservation institutions, and foundations responsible for managing monumental buildings (Lazzeri, A. et al., 2016). The objective of the project was to develop and test new products for the preservation of stone-based monuments. Specifically, the focus was on formulating and evaluating consolidating and protective materials.

In terms of consolidants, the project explored water-based formulations that consisted of nano-inorganic or nano-hybrid dispersions. These formulations incorporated materials such as nano-silica, nano-titania, nano-hydroxyapatite, nano-lime, and nano-magnesium. Additionally, synergistic combinations of organic and inorganic compounds were investigated (Lazzeri, A. et al., 2018).

To enhance the functional properties of organic polymers, new organic polymeric consolidants were employed either alone or in conjunction with inorganic nanoparticles. These consolidants aimed to improve characteristics such as hydrophobic behavior, cohesivity, and adhesivity. By addressing the photooxidative degradation pattern that occurs during outdoor aging, these materials provided enhanced stability by generating inert or volatile products (Lazzeri, A. et al., 2018).

As part of the Nano-Cathedral project, an analysis and classification of the stones used in the construction of buildings was conducted to understand their historical quarrying origins as building materials. This analysis aimed to enhance the understanding of the architectural and artistic heritage and its connections to the regional context. A comprehensive protocol was developed for the identification of petrographic and mineralogical features of the stone materials. The state of conservation of the stones was evaluated, and correlations were established among the decay state, material properties, and local macro and microclimatic conditions (Lazzeri, A. et al., 2016).

To test the effectiveness of the innovative nanomaterials developed in the project, stone samples representing the selected lithotypes were obtained from quarries. These samples were subjected to laboratory tests before and after the application of consolidation and/or protection products. The evaluation process included microscopic observations, colorimetry, and spectroscopic analyses. Through these tests, the effectiveness of the treatments could be assessed (Lazzeri, A. et al., 2018).

The most promising formulations of consolidants and protective treatments were then applied to selected pilot areas within each building. Non-destructive tests were conducted to monitor the effectiveness and durability of the applied treatments. These tests aimed to ensure the long-term preservation and stability of the treated areas (Lazzeri, A. et al., 2018).

Name	Pisa	Vitoria	Wien	Koln	Ghent	Oslo
Building Period	Medieval Age	Medieval Age	Medieval Age (1140-1513)	Medieval Age (1248–ca.1520) 19^{th} Century (1842 – 1880)	Medieval Age (942-1038) 14^{th} - 16^{th} Centuries (1300-ca. - 1569)	2003-2007
Architectural Style	Pisan Romanesque	13^{th} - 16^{th} Centuries Gothic	Late Romanesque and Gothic	Gothic Neogothic	Romanesque Brabantine Gothic	Contemporary
Climate	South European / Coastal	South European / Continental	Central European / Continental	North European / Continental	North European / Coastal	Scandinavian / Coastal
Main Lithotypes Classes	• Mount Pisano marble • Black limestones • Apuan marble • Proconnesi	• umachella from Ajarte • andstone from Elguea • alcarenite from Olarizu	• Limestones from Leithamountains and Vienna, • Few siliceous sandstones from Lower Austria	• Drachenfels Trachyte • Schlaitdorf Sandstone • Obernkirchen	• Arenaceous limestone belonging to the Lede Formation (Belgium) • Belgian and French	• White Carrara marble

	an marble • Calcarenite • Granitoid rocks • Serpentinite			Sandstone • Savonnieres Limestone • Volcanic Tuffstones • Basalt lava	limestones as replacement materials (from Gobertange, Euville, Savonnières and Massangis)	

Objectives

According to (www.nanocathedral.eu)The objective of the Nano-Cathedral project is to provide "key tools" for restoration and conservation:

- On representative lithotypes
- On European representative climatic areas
- With a time-scale/environmental approach
- With technology validated in relevant environment (industrial plant and monuments)
- Exploiting results also on modern stone made buildings.

Testing

Artificially decayed lithotype specimens for lab tests are prepared:

- Assessment of major decay in naturally weathered states and artificial ageing procedures
- Selection of thermic ageing cycles for each lithotype
- Ageing of 144 stone specimens for each of the 6 selected lithotypes

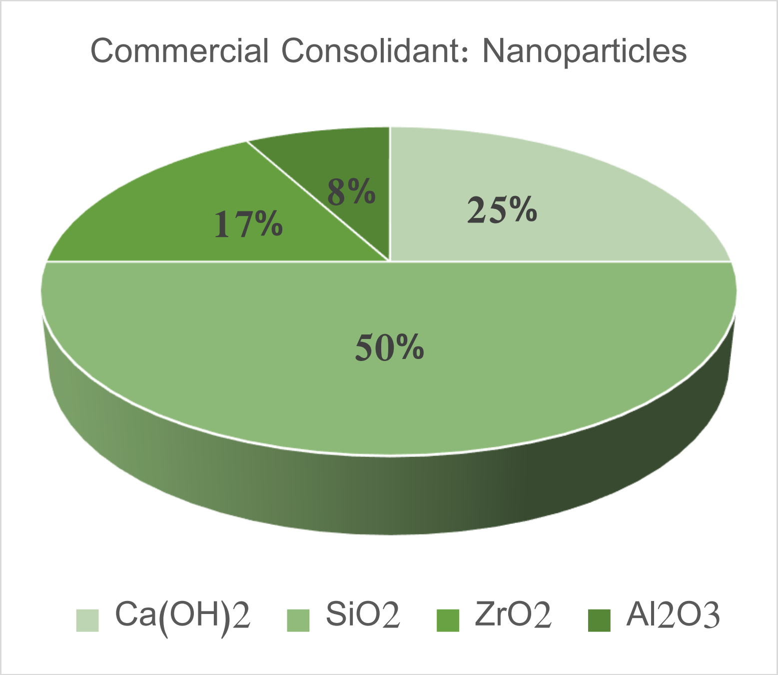
Full Program Testing:

- A systematic testing program is performed for consolidant and protective treatments to select the best ones to be applied on-site

- Application of treatments on pilot areas of monuments.
- Development of operational guidelines

Survey on commercial and research stone consolidants and protective coatings
Consolidants & Protective Coatings

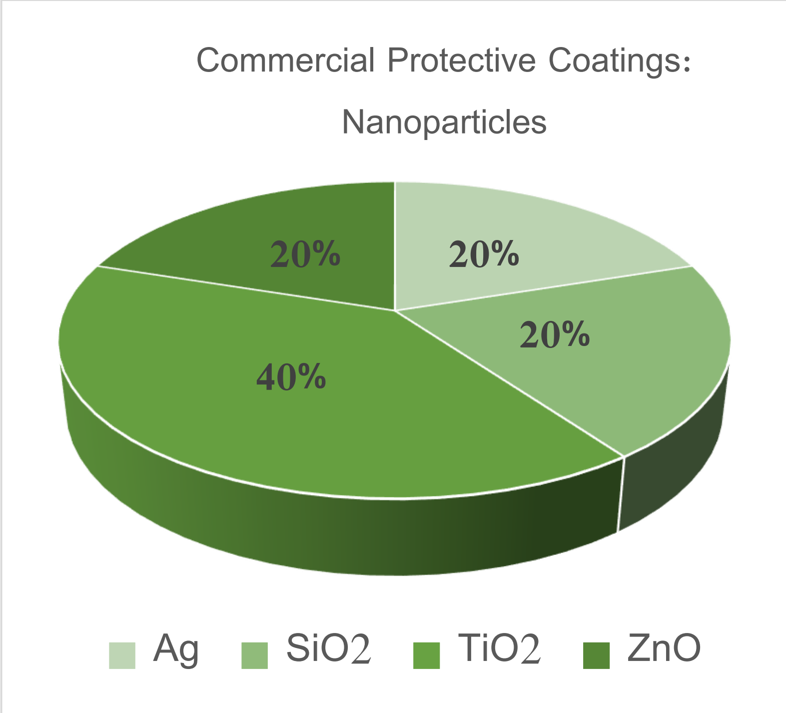
Among commercial products, the total number of different consolidant materials is 37. They can be divided in three main chemical classes: alkoxy-silane and oligomers, acrylics and low molecular weight inorganics. 12 of them contain nanoparticles in the formulation (www.nanocathedral.eu).



According to the information provided on the Nano-Cathedral project website (www.nanocathedral.eu), there are a total of 21 different protective coatings available commercially. Out of these coatings, two have antifouling properties. These coatings can be classified into five chemical classes:

- Alkyl-alkoxy-silane oligomers
- Alkyl-aryl-polysiloxanes
- Fluorinated or partially fluorinated polymers
- Low molecular weight inorganics
- Vegetable polysaccharides

Among these coatings, five formulations include nanoparticles as part of their composition. These nanoparticles likely contribute to the specific properties and performance of these coatings in terms of protection and preservation of heritage materials.



Selection of lithotypes

According to the information available on the Nano-Cathedral project website (www.nanocathedral.eu), for each cathedral involved in the project, one lithotype has been selected. However, for the Cathedral of Cologne, two lithotypes have been chosen. The selection of these lithotypes is based on several factors, including their petrographic properties, their representability for the building, and their relevance in the European context. This approach ensures that the project results can be applied on a large scale and have wider applicability beyond individual cathedrals, contributing to the preservation and conservation of heritage materials throughout Europe.

Building	**Stone name**	**Lithotype**
Cathedral of Vitoria-Gasteiz	Ajarte	Fossil limestone
Cathedral of Ghent	Balegem	Sandy limestone
Cathedral of Cologne	Obernkirchen	Sandstone
	Schlaitdorf	Sandstone
Cathedral of Vienna St.	Margarethen	Calcareous
		arenite
Cathedral of Pisa	Carrara marble	Marble
Oslo Opera House		

Decay Report

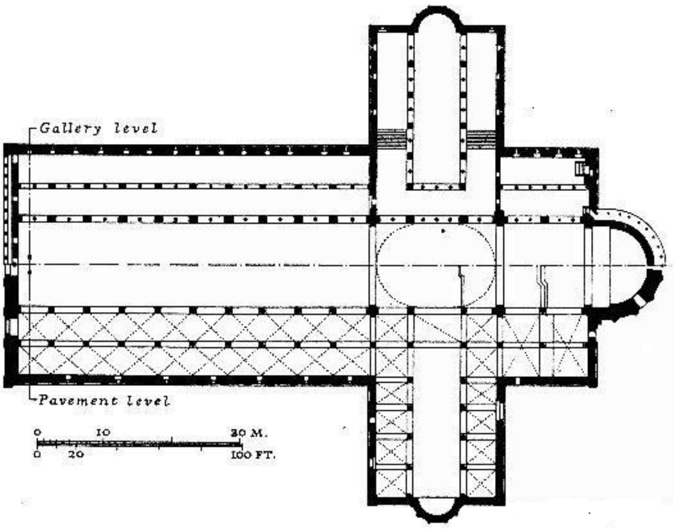
Report on decay phenomena according to ICOMOS Glossary (www.nanocathedral.eu)

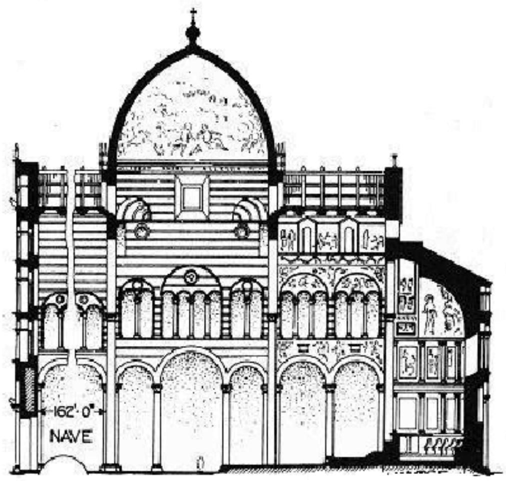
				
CRACK & DEFORMATION	**DETACHMENT**	**FEATURES INDUCED BY MATERIAL LOSS**	**DISCOLORATION & DEPOSIT**	**BIOLOGICAL COLONIZATION**
CRACK	BLISTERING	ALVEOLIZATION	CRUST	BIOLOGICAL COLONIZATION
Fracture	BURSTING	Coving	Black crust	
Star crack	DELAMINATION	EROSION	Salt crust	ALGA
Hair crack	Exfoliation	Differential erosion	DEPOSIT	LICHEN
Craquele	DISINTEGRATION	Loss: (1) of components (2) of matrix	DISCOLOURATION	MOSS
Splitting	Crumbling		Colouration	MOULD
DEFORMATION	Granular disintegration: (1)Powdering, Chalking (2) Sanding (3) Sugaring		Bleaching	PLANT
		Rounding	Moist area	
		Roughening	Staining	
		MECHANICAL DAMAGE	EFFLORESCENCE	
	FRAGMENTATION	Impact damage	ENCRUSTATION	
	Splintering	Cut	Concretion	
	Chipping	Scratch	FILM	
	FRAGMENTATION	Abrasion	GLOSSY ASPECT	
	Splintering	Keying	GRAFFITI	
	Chipping	MICROKARST	PATINA	
	PEELING	MISSING PART	Iron rich patina	
	SCALING	Gap	Oxalate patina	
	Flaking	PERFORATION	SOILING	
	Contour scaling	PITTING	SUBFLORESCENCE	

Santa Maria Cathedral – Pisa

Cathedral of Pisa

- Architect: Buscheto di Giovanni Giudice
- Location: Pisa, Italy
- Date: 1063 to 1350
- Building Type: church complex
- Climate: Mediterranean
- Context: church complex and tower
- Style: Romanesque
- Construction System: bearing masonry, cut stone, white marble






Lithotypes and decay phenomena

The Cathedral of Pisa was built using different lithotypes such as (www.nanocathedral.eu):

- Mount Pisano marble
- Black Limestone
- Apuan marble
- Proconnesian marble
- Calcarenite granitoid rocks
- Serpentinite.

The surfaces of the cathedrals are susceptible to degradation due to various factors, including climatic conditions and air pollutants. These factors contribute to the formation of cracks on the surface, such as hair cracks, star-shaped cracks, and craquelure. Additionally, delamination, which is the separation of layers or fragments from the surface, can be observed. Disintegration of the stone may occur in the form of crumbling, sugaring (formation of powdery residue), and granular disintegration. These degradation phenomena pose challenges to the preservation and conservation of the cathedrals' stone surfaces and emphasize the need for effective treatments and interventions to mitigate further deterioration. The Nano-Cathedral project aims to address these issues through the development and application of innovative nanomaterials for consolidation and protection.

The material of the cathedrals is subject to erosion phenomena, which gradually wear away the surface. Impact damages and gaps contribute to the loss of material, leading to structural vulnerabilities. In certain areas, pitting, which is the formation of small cavities or depressions, can be observed. Black crusts, likely formed from the deposition of pollutants and biological growth, can be found in various areas. Staining caused by the oxidation of iron and bronze is also present. Additionally, incrustations and patinas, which are layers of accumulated debris or corrosion products, may be observed. The surfaces are further affected by soiling deposits, which accumulate on areas that are shielded from wind and rain. These various forms of deterioration highlight the need for appropriate conservation strategies to protect and restore the cathedrals' surfaces. The Nano-Cathedral project aims to develop nanomaterial-based solutions to address these specific issues and improve the preservation of the heritage structures.

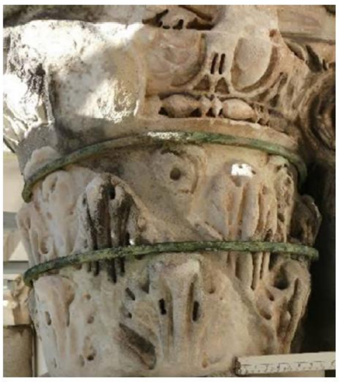
The biological colonization of the monument is a significant concern, with various forms of organisms impacting the surfaces. Algae, lichens, moss, and plants can be found growing in the joints between the stone slabs. These organisms not only detract from the aesthetic value of the monument but also contribute to the degradation and deterioration of the stone materials over time. Their growth can lead to increased moisture retention, which promotes the development of cracks, disintegration, and other forms of damage. Effective measures for controlling and preventing biological colonization are crucial to the preservation and maintenance of the monument's surfaces. The Nano-Cathedral project, with its focus on developing nanomaterial-based treatments, aims to provide innovative solutions for combating biological colonization and minimizing its detrimental effects on the heritage structures.

SPLITTING

Splitting of a marble element

Lithotype: Apuan marble

ACTURE



***Fracture** of a capitel*

Lithotype: Apuan marble

FLAKING

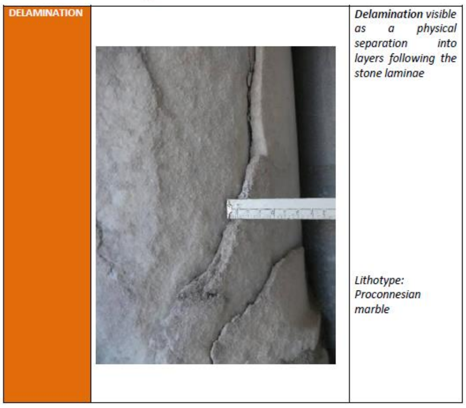
Flaking appearing as very thin scaling

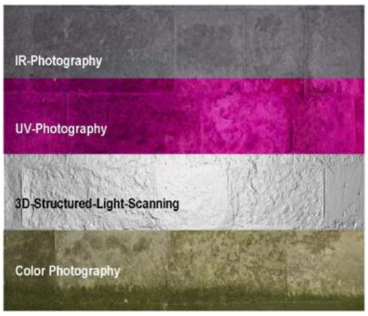
Lithotype: Mount Pisano marble

EROSION

Rounding of the stone work of the capital

Lithotype: Apuan marble





Scanning & Trial Areas

The Monitoring Campaign I at the Cattedrale di Santa Maria in Pisa had the objective of documenting the condition of the surfaces prior to any treatment with nanotechnology or any preparatory measures such as cleaning. This monitoring campaign involved conducting a comprehensive assessment and analysis of the surfaces, including their deterioration, cracks, erosion, biological colonization, and other forms of damage. By documenting the initial condition of the surfaces, it serves as a baseline for evaluating the effectiveness and impact of the subsequent nanotechnology treatments and allows for a comparison of the before and after results. This monitoring approach provides valuable data and insights for assessing the performance and durability of the nanomaterial-based treatments applied to the cathedral surfaces. During the Monitoring Campaign I at the Cattedrale di Santa Maria in Pisa, two different methods of documentation were employed based on the accessibility of the trial areas. For areas with good accessibility and sufficient space for bulky equipment, photographs were taken using various techniques and high-resolution quality. This allowed for detailed imaging and documentation of the surfaces, capturing the condition of the areas with precision.

However, in areas that posed challenges in terms of accessibility, such as towers or locations with limited space, a different approach was adopted. These areas were photographed using a lower resolution quality, which required less equipment. While the image quality may have been reduced, this approach allowed for documentation of the surfaces in difficult-to-reach areas where the use of bulky equipment was not feasible.

By employing different documentation methods based on the accessibility of the trial areas, the Monitoring Campaign I aimed to ensure comprehensive documentation of the cathedral surfaces, capturing the condition of both easily accessible and challenging locations.

High resolution Version

If possible all areas should be documented in high resolution quality in order to get best detail and analytical information of the surface. Following techniques were used:

- Color photography (with full frame Hasselblad H2D digital camera and Broncolor flash system)
- UV-photography (with full frame Hasselblad H2D digital camera and Broncolor UV-flash system)
- IR-photography (with special Canon EOS 5 Mark II - IR camera and Broncolor flash system)
- Structured-light-scanning (high resolution 3D-Documentation with Steinbichler Comet L3DScanner)
- Terrestrial 3D-scanning of surrounding areas to locate the monitoring areas (Faro Focus X120)

To maintain consistent light conditions and ensure accurate color representation across all trial areas and monitoring campaigns, a standard protocol was established. In order to achieve this, all photographs were taken at night using a broncolor grafit A4 flash system, which provided controlled and uniform lighting. The flash system included two flashbulbs and soft boxes to create a smoother light distribution.

In addition to the lighting setup, color calibration was an important aspect of the documentation process. To achieve accurate color reproduction, a Kodak color chart was included in the photographs. The color chart served as a reference point for color calibration, allowing for precise color adjustments during the analysis and comparison of images.

By implementing these measures, such as capturing images at night with controlled lighting and using a color chart for calibration, the monitoring campaign aimed to ensure consistent and accurate documentation of the trial areas in terms of light conditions, color temperature, and brightness, facilitating reliable analysis and comparison of the images.

Yes, you have accurately summarized the measures taken to maintain consistent light conditions and ensure accurate color representation during the monitoring campaign. By using the broncolor grafit A4 flash system with two flashbulbs and soft boxes, the lighting was controlled and uniform across all trial areas. This helped to minimize variations in lighting and ensure consistent image quality. The inclusion of a Kodak color chart in the photographs allowed for color calibration. The color chart provided a reference for accurate color reproduction, enabling precise adjustments during image analysis and comparison. This ensured that the colors captured in the photographs were faithfully represented and consistent across different areas and monitoring campaigns. Overall, these measures were implemented to achieve reliable and standardized documentation of the trial areas, enabling accurate analysis and comparison of the images over time.

The flash system and the structured-light scanner (SLS) used in the monitoring campaign have specific space and accessibility requirements. Due to their size and working distance, they need approximately 6 m^2 of space in front of the trial area to ensure proper functioning and accurate measurements. This space allows for the necessary distance between the instruments and the trial area, which is crucial for capturing detailed data. Moreover, both the flash system and the SLS are heavy, weighing around 25 kg each. As a result, they need to be transported in large cases, which may limit their usability in areas with limited accessibility. Given these factors, the instruments are primarily used for trial areas that have good accessibility, where there is sufficient space to accommodate the equipment and allow for the required working distance. In areas with restricted access or limited space, alternative documentation methods may be employed to capture the necessary information.

By considering the equipment's size, weight, and spatial requirements, the monitoring campaign ensures that the flash system and SLS are utilized effectively in areas where they can provide accurate and comprehensive data. After capturing the photographs using the flash system, a post-processing step was undertaken to align and straighten out the images to match the 3D surface obtained from the structured-light scanner (SLS). This alignment process ensured that the images could be accurately overlaid onto the 3D surface. By combining the aligned images with the topography of the surface, which was captured by the 3D model generated by the SLS, a comprehensive dataset was created. This dataset consisted of color, UV, and IR images overlaid onto the 3D surface, providing a detailed representation of the trial areas.

The alignment and overlaying of images onto the 3D surface, along with the incorporation of topographical information, facilitated the comparability of the trial areas. This approach created a comprehensive and standardized basis for analyzing and evaluating the conditions of the surfaces, allowing for accurate comparisons between different areas and monitoring campaigns.

Overall, this method of aligning and overlaying images onto the 3D surface of the SLS, combined with the topographical data, enhanced the accuracy and reliability of the analysis and comparison of the trial areas in the monitoring campaign.

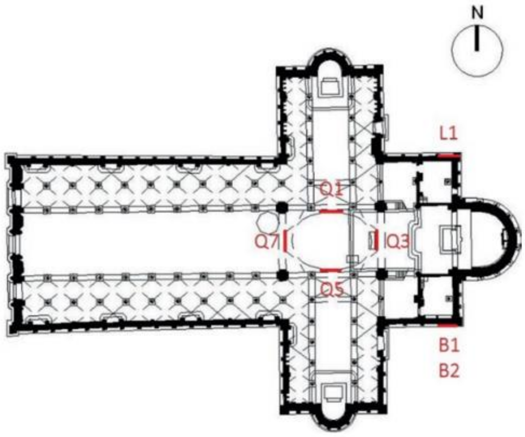
Light Version

Areas at towers or with difficult accessibility were documented with less equipment. Following techniques were used (www.nanocathedral.eu):

- Color photography (with full frame Hasselblad H2D digital camera and Broncolor flash system)
- IR-photography (with special Canon EOS 5 Mark II - IR camera and Broncolor flash system)
- Terrestrial 3D-scanning (with Faro Focus X120)

I apologize for the incorrect information provided earlier. Based on the information you provided from the nanocathedral.eu website, it appears that the documentation process does not involve the use of a flash system or structured-light scanner. Instead, it seems that the documentation process has some limitations and disadvantages. Unfortunately, without further information from the website or additional context, I am unable to provide specific details about the disadvantages of the documentation method used. It would be best to refer to the nanocathedral.eu website or any accompanying documentation for more comprehensive information regarding the limitations of the documentation process described.

Trial Areas



1. **Trial Area B1**

Trial area B1 is located on the south side, exposure also south, in the first order of the choir.

According to the information provided on the nanocathedral.eu website, the area in question, located in the choir of the Cathedral, is believed to be the earliest stage of construction dating back to the eleventh century. It is notable for the use of reused stones and marble spolia as building materials. The masonry in this area contains ancient marbles with high reliefs, such as flowers and spirals, as well as classical epigraphs. Additionally, fragments of tendrils from the early medieval period can be found in the pillar of this area. For further details and in-depth information, it is recommended to refer to the nanocathedral.eu website or related sources.

According to the information provided on the nanocathedral.eu website, the trial area in question is located at a height of approximately 5 meters and can be accessed via scaffolding. However, due to the width of the area and the presence of scaffolding tubes, capturing the trial area properly with the scanner and camera can be challenging. As a result, there may be interpolations in the scanning data, which could affect the accuracy of the captured 3D surface information. Additionally, shadows may be present in the photographs due to the obstructed view caused by the scaffolding. These limitations should be taken into consideration when analyzing the documentation data. For more detailed information and specific procedures, it is advisable to refer to the nanocathedral.eu website or related sources.

Condition of the surfaces:

According to the information provided on the nanocathedral.eu website, the Apuan marble in the trial area exhibits certain characteristics. Black crusts can be observed on some protected parts of the marble, indicating the presence of surface deposits or pollutants. The marble also shows signs of sanding, particularly in the area of the high reliefs, where the surface has been abraded or worn down, possibly due to weathering or human activity. In other areas, the marble may display a weaker form of sanding or powdering, indicating a gradual loss of material. It is mentioned that the joints and gaps in the marble are filled with Portland cement, which is a common type of cement used for construction purposes. These observations provide insights into the condition and material composition of the Apuan marble in the trial area. For more detailed information and specific analysis, it is advisable to refer to the nanocathedral.eu website or related sources.

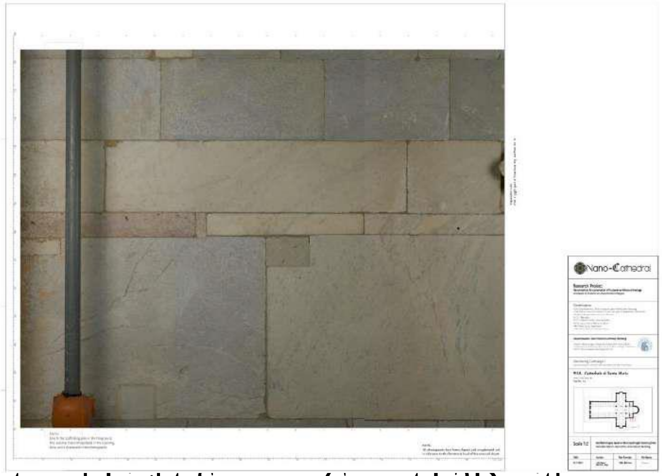
According to the information provided on the nanocathedral.eu website, the Monte Pisano marble in the trial area exhibits certain characteristics. There is evidence of weak erosion, which indicates the gradual wearing away or weathering of the marble surface. This erosion may be uneven or differential, meaning that some areas may show more significant decay than others. Additionally, there is a mention of weak powdering, suggesting that the marble surface is gradually disintegrating into a powdery or granular form. Similar to the Apuan marble, the joints and gaps in the Monte Pisano marble are filled with Portland cement, which is a common filler material used in construction. These observations provide insights into the condition and material composition of the Monte Pisano marble in the trial area.

According to the information provided on the nanocathedral.eu website, the Breccia corallina in the trial area exhibits certain characteristics. There is evidence of weak powdering, indicating that the surface of the stone is gradually disintegrating into a powdery or granular form. This powdering may be a result of weathering or decay processes affecting the stone. Additionally, similar to the previous marble types mentioned, the joints and gaps in the Breccia corallina are filled with Portland cement, which is a common filler material used in construction. These observations provide insights into the condition and material composition of the Breccia corallina in the trial area.

Based on the available information, there are no specific documents or records regarding recent treatments of conservation for the trial area in question. However, it is noted that a restoration took place in the years 1939-40, during which Portland cement was used and mechanical cleaning of the surfaces was carried out. This restoration indicates that efforts were made in the past to address the condition of the area and ensure its preservation. It is possible that more recent conservation treatments have taken place but may not be documented or publicly available. For comprehensive and up-to-date information on the recent treatments of the trial area, it is advisable to consult relevant conservation authorities or professionals involved in the ongoing preservation of the cathedral.

Size of documented area: 392 x 200 cm

Material: Apuan marble, Monte Pisano marble, Bloch Limestone



The trial area was 3D-scanned using a Structured-Light-Scanner Comet L3D with a resolution of 0.3 mm. The scanning process involved capturing 57 individual scans of the area. A 800mm lens was used during the scanning process to ensure detailed and accurate data capture. The structured-light scanning technique involves projecting a pattern of structured light onto the surface and capturing the deformation of the pattern, which allows for the creation of a detailed 3D model of the scanned area. The resulting scans provide a comprehensive representation of the geometry and surface details of the trial area, facilitating further analysis and documentation of its condition.

To ensure comprehensive photographic documentation of the trial area, the process was divided into four separate shots to capture the entire width of the area. All photographs, except for the UV documentation, were taken using a modeling light.

For color photography, a Hasselblad H2 with an ixpress CFH digital body (39 megapixels) was used. The lens used was a Hasselblad HC 50mm lens, with an ISO setting of 50, focal ratio of F/11, and an exposure time of 1/125 sec. The measurement mode used was center-weighted. The flash system employed was the Broncolor grafit A4 with a stereo flash setup. The right flashbulb was equipped with a softbox measuring 60x100 cm, with a focal ratio of 5.0. The left flashbulb also had a softbox measuring 60x100 cm, with a focal ratio of 5.0. The photograph was taken with a single flash impulse.

For UV photography, the same Hasselblad H2 camera with ixpress CFH digital body was used, along with the Hasselblad HC 50mm lens. The ISO setting was 50, focal ratio was F/11, and the exposure time was 1/125 sec. The measurement mode used was center-weighted. The flash system employed was the Broncolor grafit A4 with two flashbulbs. The right flashbulb had a softbox measuring 60x100 cm, with a focal ratio of 9.0. The left flashbulb also had a softbox measuring 60x100 cm, with a focal ratio of 9.0. The photograph was taken with multiple flash impulses.

For IR photography, a Canon EOS 5D Mark II camera with a resolution of 21 megapixels was used, along with a Canon 35mm lens. The ISO setting was 100, focal ratio was F/11, and the exposure time was 1/160 sec. The measurement mode used was evaluative metering. The flash system employed was the Broncolor grafit A4 with two flashbulbs. The right flashbulb had a softbox measuring 60x100 cm, with a focal ratio of 5.0. The left flashbulb also had a softbox measuring 60x100 cm, with a focal ratio of 5.0. The photograph was taken with a single flash impulse.

By using this combination of equipment and settings, the photographic documentation aimed to capture detailed color, UV, and IR images of the trial area, ensuring accurate representation and facilitating further analysis and comparison.

2. Trial Area B2

Trial area B2 is located on the first order of the choir, specifically on the south side, with a south-facing exposure. It is situated directly beneath trial area B1, at ground level. Access to trial area B2 is possible through or behind scaffolding. However, due to the width of the area, some parts of the trial area are obstructed by scaffolding tubes, making it challenging to capture accurate scans and photographs. As a result of the obstructed view, there may be interpolations in the scanning data, which could affect the accuracy of the 3D model generated. Shadows may also be present in the photographs due to the presence of scaffolding. The area of the choir in this position is considered the first stage of construction dating back to the eleventh century. During this phase, reused stones and spolia from ancient, early medieval, and medieval times were employed as building materials. It represents a significant historical and architectural aspect of the cathedral's construction history.

Condition of the surfaces:

According to the information provided on www.nanocathedral.eu, the following is an overview of the condition and treatment history of the specified materials in the documented area:

1. Apuan Marble:

- Condition: The marble exhibits small cracks, fissures, and losses.

- Treatment: The joints and gaps in the marble are filled with Portland cement.

2. Monte Pisano Marble:

- Condition: The marble shows signs of weak erosion with differential decay and weak powdering. It also has small cracks and fissures.

- Treatment: Similar to Apuan marble, the joints and gaps in the Monte Pisano marble are filled with Portland cement.

3. Bloch Limestone:

- Condition: The limestone displays small cracks and fissures.

- Treatment: The joints and gaps in the Bloch Limestone are filled with Portland cement.

Recent Treatments of Conservation:

According to the available information, there are no records of recent treatments for the documented area. However, in the years 1939-40, a restoration project took place, involving the use of Portland cement and mechanical cleaning of the surfaces.

Size and Material:

The documented area has dimensions of 392 x 200 cm and consists of a combination of Apuan marble, Monte Pisano marble, and Bloch Limestone. 3D-scanning: Structured-Light-Scanner Comet L3D in a resolution of 0.3 mm (800mm lens). The area was scanned with 49 single scans. Due to the Trial Area’s width, all photographic documentation had to be subdivided into four single shots. All photographs except UV were done with modeling light. There might occur changes in color at the junction of the single shots (www.nanocathedral.eu).

Color photography: single shot taken with Hasselblad H2 with ixpress CFH digital body (39 megapixel); lens: Hasselblad HC 50 mm; ISO: 50; focal ratio: F/11; exposure time: 1/125 sec.; measurement mode: centerweighted (www.nanocathedral.eu).

Flash system: Broncolor grafit A4 with stereo flash; setup of right flashbulb: soft box 60x100 cm; focal ratio: 5.0; setup of left flashbulb: soft box 60x100 cm; focal ratio: 5.0; taken with single flash impulse (www.nanocathedral.eu).

UV-photography: single shot taken with Hasselblad H2 with ixpress CFH digital body (39 megapixel); lens: Hasselblad HC 50 mm; ISO: 200; focal ratio: F/5.6; exposure time: 1/90 sec.; measurement mode: centerweighted (www.nanocathedral.eu).

Flash system: Broncolor grafit A4 with two flashbulbs; setup of right flashbulb: soft box 60x100 cm; focal ratio: 9.0; setup of left flashbulb: soft box 60x100 cm; focal ratio: 9.0; taken with multi flash impulse (www.nanocathedral.eu).

IR- photography: single shot taken with Canon EOS 5D Mark II (21 megapixel); lens: Canon 35mm; ISO: 100; focal ratio: F/11; exposure time: 1/160 sec.; measurement mode: evaluative metering. Flash system: Broncolor grafit A4 with two flashbulbs; setup of right flashbulb: soft box 60x100 cm; focal ratio: 5.0; setup of left flashbulb: soft box 60x100 cm; focal ratio: 5.0; taken with single flash impulse.

3. Trial Area L1

Trial Area L1 is situated in the first bay of the choir, specifically on the corner of the cornices, at a height of approximately 12 meters. It is accessible via scaffolding, and its orientation and exposure are both towards the north. This particular area of the choir is believed to represent the initial phase of the Cathedral's construction, dating back to the eleventh century. It is positioned above the first work site, where stones and spolia marble from previous structures were utilized as building materials. For more detailed information.

Condition of the surfaces:

In Trial Area L1, the Apuan marble exhibits several characteristics and issues. The surface is covered with black crusts in certain protected parts, indicating the presence of surface contaminants. Additionally, there is a significant attack of biological film, particularly algae, which can contribute to the degradation of the marble. The marble also displays a strong sanding effect, likely due to weathering processes over time.

To address the gaps and joints between the marble elements, Portland cement has been used as a filler material. This helps to stabilize the structure and maintain the integrity of the architectural element.

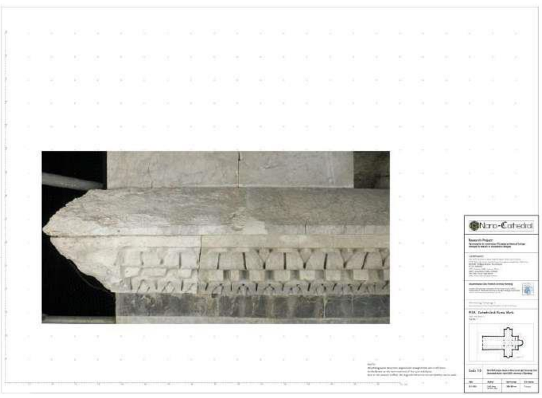
In Trial Area L1, the Monte Pisano marble presents several concerning conditions. There is a strong attack of biological film, specifically algae, which can contribute to further deterioration of the marble surface. The marble also exhibits advanced erosion with differential decay, resulting in powdering and scaling of the material. These decay processes can compromise the structural integrity and aesthetic appeal of the marble.

To address the gaps and joints between the marble elements, Portland cement has been used as a filler material. This helps to stabilize the structure and prevent further damage caused by water infiltration and movement of the architectural elements.

Regarding recent conservation treatments, there are no documented records available. However, a restoration work was carried out in 1939-40, which involved mechanical cleaning of the surfaces and the use of Portland cement to fill joints and gaps. These treatments were likely implemented to address existing deterioration issues and ensure the stability of the marble elements.

Size of documented area: Monte Pisano marble: 850 x 220 mm / Apuan marble: 570 x 260 mm

Material: Monte Pisano marble / Apuan marble



In Trial Area L1, the following documentation techniques were employed:

1. 3D Scanning: The area was scanned using a Structured-Light-Scanner Comet L3D with an 800mm lens, providing a resolution of 0.3 mm. A total of 14 single scans were performed to capture the geometry and surface details of the area.

2. Color Photography: Color photographs were taken using a Hasselblad H2 camera with an ixpress CFH digital body, featuring a 39-megapixel resolution. The lens used was the Hasselblad HC 50mm, with settings including ISO 50, focal ratio of F/11, and an exposure time of 1/125 sec. The measurement mode employed was centerweighted.

3. Flash System: A Broncolor grafit A4 flash system with stereo flash was utilized for color photography. The right flashbulb was equipped with a soft box measuring 60x100 cm and had a focal ratio of 5.0, while the left flashbulb had the same specifications. The photographs were taken using a single flash impulse.

4. UV Photography: UV photographs were captured using the same Hasselblad H2 camera and ixpress CFH digital body, with settings including ISO 200, focal ratio of F/5.6, and an exposure time of 1/60 sec. The measurement mode employed was centerweighted.

5. Flash System: The Broncolor grafit A4 flash system with two flashbulbs and soft boxes measuring 60x100 cm each was used for UV photography. Both flashbulbs had a focal ratio of 9.0, and the photographs were taken using a multi-flash impulse.

6. IR Photography: Infrared (IR) photographs were taken using a Canon EOS 5D Mark II camera with a 21-megapixel resolution. The lens used was the Canon 35mm, with settings including ISO 100, focal ratio of F/13, and an exposure time of 1/160 sec. The measurement mode employed was evaluative metering. The flash system used for IR photography was the Broncolor grafit A4, equipped with two flashbulbs and soft boxes measuring 60x100 cm each. The right and left flashbulbs both had a focal ratio of 5.0, and the photographs were taken using a single flash impulse. These documentation techniques were employed to capture the visual and surface characteristics of Trial Area L1, providing detailed information for analysis and comparison.

Trial Area Q – Dome

In the area located on the cathedral's dome, at a height of approximately 37 meters, the documentation process faced certain limitations due to the challenging accessibility. As a result, the full equipment, including the Structured-Light-Scanner and flash system, could not be brought up to the site. Instead, a light version of documentation was utilized to capture the necessary information. The area was divided into four sub-areas: Q1 facing north, Q3 facing east, Q5 facing south, and Q7 facing west. Due to the height and narrow scaffolding, the equipment could not be installed in these sub-areas. The specific techniques used for documentation in this case are not mentioned in the provided information. However, it can be inferred that alternative methods or tools were employed to capture the required data, given the constraints of the location.

Trial Area Q1

Trial area Q1, situated on the north side of the cathedral's dome, is an important section dating back to the fourteenth century. However, due to the limited width and constrained working space, capturing this area accurately with the scanner and camera was challenging. Several parts of the trial area were obstructed by scaffolding tubes, making it difficult to obtain proper scans and photographs.

As a result of the restricted access and obstructions, there are interpolations in the scanning data and shadows present in the photographs. These factors hindered the alignment and straightening process of the photographs, preventing the generation of a fully aligned and straightened representation of the area. Despite these limitations, efforts were made to document the trial area to the best extent possible given the circumstances. While some compromises may have been necessary, the available data can still provide valuable insights into the architectural and historical aspects of the site. For more detailed information and a visual representation of the trial area, I recommend referring to the provided website (www.nanocathedral.eu) for the specific documentation of Trial Area Q1 on the north side of the cathedral's dome.

Condition of the surfaces:

In Trial Area Q1, which features Apuan marble, several observations can be made about the condition of the marble. The surface of the marble in protected parts is covered with black crusts, indicating the presence of accumulated dirt or other substances. Additionally, there is a strong attack of biological film, specifically algae, which can contribute to the discoloration and deterioration of the marble. The marble also exhibits moderate powdering and erosion, suggesting some level of degradation over time. This could be a result of natural weathering processes or environmental factors. Furthermore, there are little cracks, fissures, and losses present in the marble, indicating structural weaknesses and potential areas of concern for conservation efforts.

Recent treatments of conservation: There are no documents regarding recent treatments.

Size of documented area: 400 x 430 cm^2

Material: Monte Pisano marble / Apuan marble

Low resolution version for Q1

In Trial Area Q1, the documentation process involved the use of different equipment and techniques for 3D scanning and photography. Here are the details: 3D Scanning: The Faro Focus X120, a terrestrial laser scanner, was used. It has a resolution of 3 mm at a distance of 10 m. Four single scans were performed to capture the trial area. This scanning method allows for the creation of a detailed point cloud representation of the area, which can be used for further analysis and documentation.

Color Photography: Canon EOS 5D Mark II with a 21-megapixel resolution was used for color photography. The lens used was Canon 30mm, and the settings included ISO 200, focal ratio F/11, and exposure time ranging from 1/60 to 1/80 seconds. The measurement mode used was evaluative metering. No flash system was employed, and the photographs were taken during daylight.

IR Photography: Canon EOS 5D Mark II with a 21-megapixel resolution was also used for infrared (IR) photography. The lens used was Canon 30mm, and the settings included ISO 100, focal ratio F/11, and exposure time ranging from 1/20 to 1/50 seconds. The measurement mode used was evaluative metering. No flash system was employed, and the photographs were taken during daylight.

These techniques and equipment were used to capture both the 3D geometry and visual appearance of Trial Area Q1 in a comprehensive manner. The combination of 3D scanning and photography allows for a detailed documentation and analysis of the area, aiding in conservation and restoration efforts.

4. Trial Area Q3

Trial Area Q3 is situated on the east side of the cathedral's dome. Its orientation and exposure are also towards the east. This particular area dates back to the fourteenth century, representing an important historical period in the cathedral's construction.

However, capturing Trial Area Q3 presented some challenges due to its width and the limited working space available. Certain parts of the area were obstructed by scaffolding tubes, making it difficult to obtain accurate scans and photographs. As a result, there are interpolations in the scanning data, which means that some areas may lack precise details. Additionally, shadows can be observed in the photographs, further impacting the clarity and alignment of the images.

Despite these limitations, the documentation process aimed to capture as much information as possible, even though aligning and straightening out the photographs proved to be a challenge. The documentation efforts were conducted in order to provide a comprehensive record of Trial Area Q3 and contribute to the ongoing conservation and restoration work at the cathedral.

Condition of the surfaces:

In Trial Area Q3, which is composed of Apuan marble, several characteristics and conditions have been observed. The marble surface in protected parts is covered with black crusts, indicating the presence of accumulated organic matter. There is also a strong attack of biological film, specifically algae growth, which further affects the appearance of the marble. Additionally, the Apuan marble exhibits moderate levels of powdering and erosion. This suggests that the surface has experienced some degree of weathering and deterioration over time. The presence of little cracks, fissures, and losses further contributes to the overall condition of the marble in this area.

These observations highlight the importance of conservation and restoration efforts to address the deteriorated state of the Apuan marble in Trial Area Q3. By addressing the issues of crusts, biological film, powdering, erosion, cracks, fissures, and losses, appropriate measures can be taken to preserve and restore the marble's integrity and aesthetic value.

Recent treatments of conservation: There are no documents regarding recent treatments.

Size of documented area: 400 x 430 cm2

Material: Apuan marble

For the documentation of Trial Area Q3, the following methods and equipment were used:

3D-Scanning: The Faro Focus X120, a terrestrial laser scanner, was utilized. It has a resolution of 3 mm on a 10 m distance, providing detailed 3D data of the area. Four single scans were conducted to capture the complete Trial Area Q3.

Color photography: Canon EOS 5D Mark II, a 21-megapixel camera, was employed for color photography. The lens used was Canon 30mm, and the ISO was set to 100. The focal ratio was F/11, and the exposure time varied between 1/30 and 1/80 sec. The measurement mode used was evaluative metering. No flash system was used, and the photographs were taken during daytime lighting conditions.

IR-photography: Similar to color photography, the Canon EOS 5D Mark II camera with a 21-megapixel resolution was used for infrared photography. The lens used was Canon 30mm, and the ISO was set to 100. The focal ratio was F/11, and the exposure time varied between 1/25 and 1/40 sec. The measurement mode used was evaluative metering. No flash system was employed, and the photographs were taken during daytime lighting conditions.

These methods and equipment were employed to document Trial Area Q3 in order to capture detailed 3D data, color information, and infrared images. This documentation will aid in the assessment and analysis of the Apuan marble's condition and assist in developing appropriate conservation and restoration strategies.

5. Trial Area Q5

Trial Area Q5, located on the south side of the dome of the cathedral, has the following characteristics:

- Orientation: South

- Exposure: South

- Dating: Fourteenth century

Due to the limited working space and the width of the trial area, capturing accurate data with the scanner and camera was challenging. Several parts of the area were obstructed by scaffolding tubes, making it difficult to obtain comprehensive scans and photographs. As a result, there may be interpolations in the scanning data and shadows in the photographs. Additionally, aligning and straightening out the photographs was not possible due to these limitations.

Condition of the surfaces:

The Apuan marble in Trial Area Q5 exhibits the following characteristics:

- Black crusts: The surface of the marble is covered with black crusts in protected parts.

- Biological film: There is a presence of a biological film, specifically algae, on the marble surface.

- Powdering and erosion: The marble shows moderate levels of powdering, indicating some degree of deterioration, as well as erosion.

- Cracks, fissures, and losses: The marble displays little cracks, fissures, and losses, suggesting structural weaknesses and damage.

These conditions are important factors to consider for conservation and restoration efforts in preserving the Apuan marble in Trial Area Q5 of the cathedral.

Recent treatments of conservation: There are no documents regarding recent treatments.

Size of documented area: 400 x 430 cm^2

Material: Apuan marble

For Trial Area Q5, the following documentation methods were used:

3D-Scanning: The Faro Focus X120, a terrestrial laser scanner, was employed for capturing the three-dimensional data. It has a resolution of 3 mm at a 10 m distance. In the case of Q5, four single scans were conducted to cover the area adequately.

Color Photography: Single shots were taken using a Canon EOS 5D Mark II camera equipped with a 21-megapixel sensor. The lens used was a Canon 30mm lens. The ISO was set to 100, focal ratio to F/11, and the exposure time ranged from 1/50 to 1/60 seconds. The measurement mode used was evaluative metering. The photographs were taken during the daytime without the use of a flash system.

IR Photography: Similarly, single shots were taken using the same Canon EOS 5D Mark II camera and Canon 30mm lens. The ISO was set to 100, focal ratio to F/11, and the exposure time ranged from 1/25 to 1/50 seconds. The measurement mode used was evaluative metering. No flash system was used, and the photographs were taken during the daytime.

These documentation techniques were employed to capture detailed 3D information and visual representations of Trial Area Q5, aiding in the assessment and analysis of its condition for conservation and restoration purposes.

6. Trial Area Q7

I apologize for the confusion. Based on the information provided, Trial Area Q5 is located on the west side of the dome of the cathedral, with a west orientation and exposure. This specific area is believed to date back to the fourteenth century.

However, capturing accurate documentation of Trial Area Q5 has been challenging due to its width and the limited working space available. The presence of scaffolding tubes obstructs certain parts of the area, making it difficult to capture complete and precise data using both the scanner and camera. As a result, there are interpolations in the scanning data and shadows in the photographs. Unfortunately, it was not possible to align and straighten out the photographs due to these limitations.

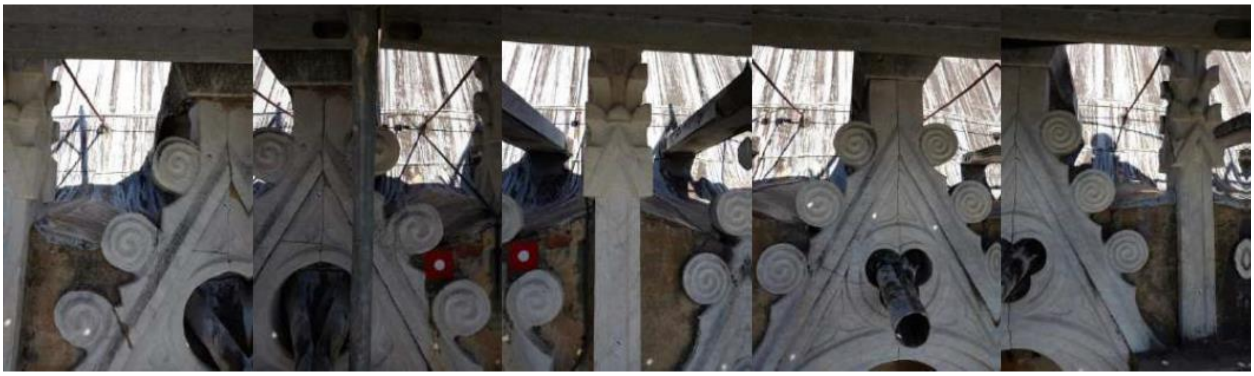
Condition of the surfaces:

Apuan marble: black crusts cover the surface in protected parts. Presence of a biological film (algae). The marble also has moderate powdering and erosion. The marble shows little cracks, fissures and losses.

Recent treatments of conservation: There are no documents regarding recent treatments.

Size of documented area: 400 x 430 cm^2

Material: Apuan marble



3D-Scanning: The area was scanned using a Faro Focus X120, which is a terrestrial laser scanner. The scanner has a resolution of 3 mm on a 10 m distance, with a specified resolution of ½ and quality of ¼. Four single scans were performed to capture the area.

Color photography: For color documentation, single shots were taken using a Canon EOS 5D Mark II camera with a 21-megapixel resolution. The lens used was a Canon 30mm lens. The camera settings were as follows: ISO 100, focal ratio of F/11, exposure time ranging from 1/80 to 1/125 sec. The measurement mode used was evaluative metering. The color photographs were taken during daytime without the use of a flash system.

IR photography: Infrared (IR) shots were taken using the same Canon EOS 5D Mark II camera with a 21-megapixel resolution and a Canon 30mm lens. The camera settings for IR photography were ISO 100, focal ratio of F/11, exposure time ranging from 1/40 to 1/50 sec. The measurement mode used was evaluative metering. Similar to color photography, the IR photographs were taken during daytime without the use of a flash system.

Testing Criteria

The European Nano-Cathedral Project aims to develop and test new nanoparticle-based products for the conservation and restoration of cultural heritage, specifically focusing on cathedrals. The project involves the formulation and testing of these products both in laboratory settings and in situ, meaning they are tested directly on the cathedrals themselves.

The project selected five cathedrals that represent different environmental conditions and lithotypes, which are the types of stone used in their construction. These cathedrals include limestone, sandstone, and marble. The Cathedral of Pisa, located in Italy, was chosen as an example representing the Mediterranean area.

The compatibility and efficiency of consolidants used in the European Nano-Cathedral Project were verified through control tests conducted before and after the application of the products. These tests were performed in dry weather conditions to minimize the potential interference of humidity on the results (Lazzeri, A., et al., 2018).

The control tests included several methods: colorimetry, water absorption tests using the Karsten tube and contact sponge, mechanical strength tests, and microscopic investigation (Lazzeri, A., et al., 2018). The Karsten tube test measures the water absorption of the stone before and after the application of a consolidant. Generally, the water absorption decreases after the application, indicating improved water resistance (Lazzeri, A., et al., 2018). Similarly, the absorption capacity decreases after the application of protective treatments, and this trend was observed across different lithotypes present in Pisa's cathedral (Lazzeri, A., et al., 2018).

The contact sponge test was found to be more efficient and reliable than the Karsten tube test for measuring water absorption capacity, especially considering Pisa's cathedral lithotypes and their conservation status. A significant decrease in water absorption was recorded after the treatment (Lazzeri, A., et al., 2018). To assess the mechanical resistance of the stone before and after the consolidating treatment, the microdrilling test was performed on Carrara marble and Monte Pisano limestone. This test measures the strength exhibited by the stone when subjected to drill penetration at a specific rotation speed, providing a value indicative of mechanical strength (Lazzeri, A., et al., 2018).

Color measurements were conducted using a spectrophotometer with the CIE lab color space, which allows for precise quantification and comparison of color properties (Lazzeri, A., et al., 2018).

Chosen Consolidants

The Consolidants according to (Lazzeri,A., et al.,2018).

- Consolidant DN, a tetraethyl silicate in isopropyl alcohol
- VP 5035, an alkyl alkoxysilane in isopropyl alcohol modified with organic compound
- NC-20C, a nano-silica in water
- NC-12C, a nano-silica suspension in water and ethanol with biocide compound.

Chosen Protective Coatings

The protectives according to (Lazzeri,A., et al.,2018).

- NC-21P, a water repellent based on nano-titania particles in water
- NC-24P, an antibacterial based on nano-silver particles in isopropanol
- NC-22P, a water repellent based on nano-titania particles in isopropanol
- NC-16P, a water repellent based on ethyl silicate and oxalic acid in 2-propanol
- NC-9P, a nano-titania suspension in water.

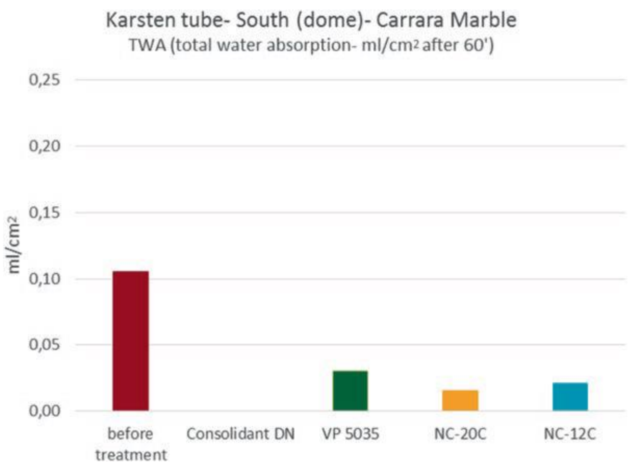
Results

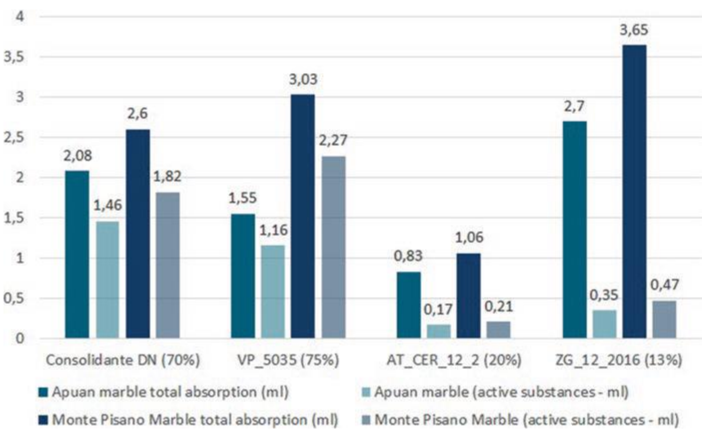
According to Lazzeri et al. (2018), the Cathedral of Pisa conducted in situ experimentation and installed three data logger devices to measure the environmental conditions. The temperature and relative humidity were recorded throughout the experimentation period to better understand the interaction between the nanoscale products and the environment.

Pisa's cathedral has completed the small-scale experimentation and is nearing completion of the second phase, which involved the application of the products and control tests on the consolidants and protectives in the designated pilot areas. The evaluation of the data obtained from the control tests is still in progress (Lazzeri, A., et al., 2018).

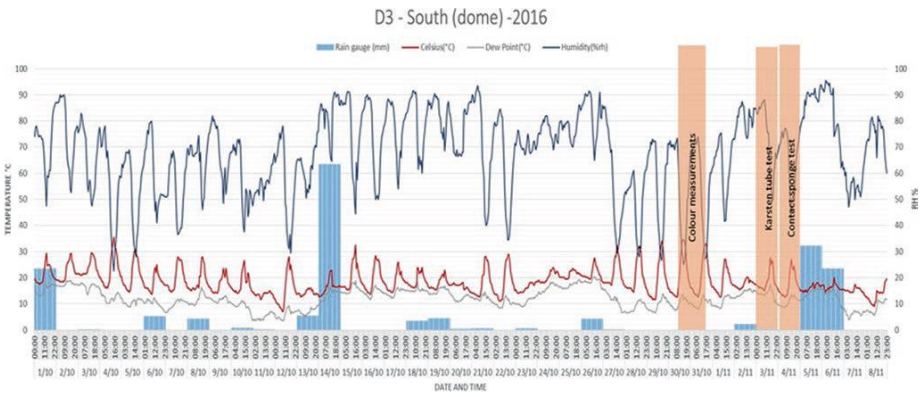
The Playground, a specific area for experimentation, focused on testing four consolidants and five protectives. Two trial areas were selected at the base of the dome to evaluate the consolidants. The tested products included Consolidant DN, which is a tetraethyl silicate in isopropyl alcohol; VP 5035, an alkyl alkoxysilane in isopropyl alcohol modified with an organic compound; NC-20C, a nano-silica in water; and NC-12C, a nano-silica suspension in water and ethanol with a biocide compound. The first two products were commercially available and served as a basis for comparison with the products specifically developed for this experimentation (Lazzeri, A., et al., 2018).

These experiments and tests conducted in the Playground aim to assess the performance and suitability of the consolidants and protectives for the preservation and conservation of Pisa's cathedral.

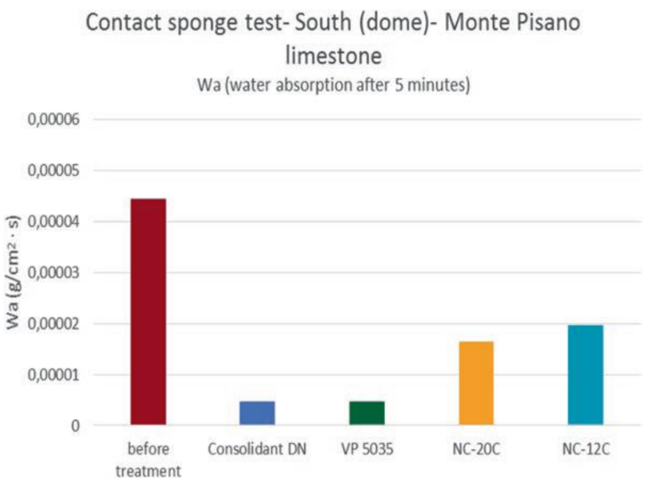




Consolidants: comparison between volume of solution and volume of active substances absorbed by the two stones (test areas 10 cm × 10 cm)

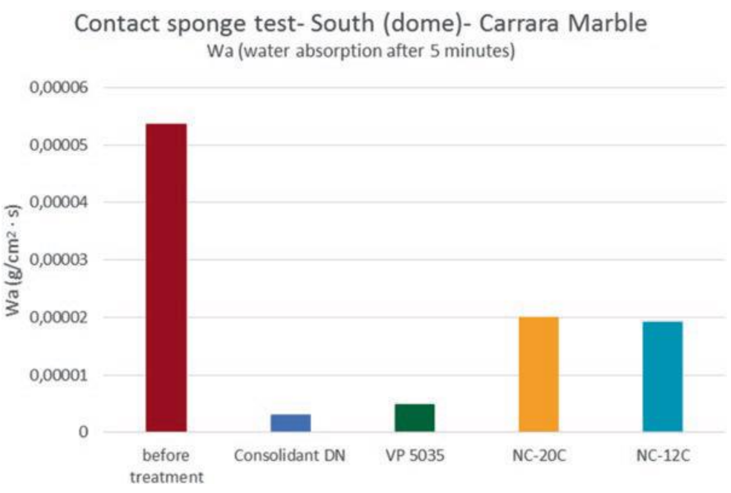


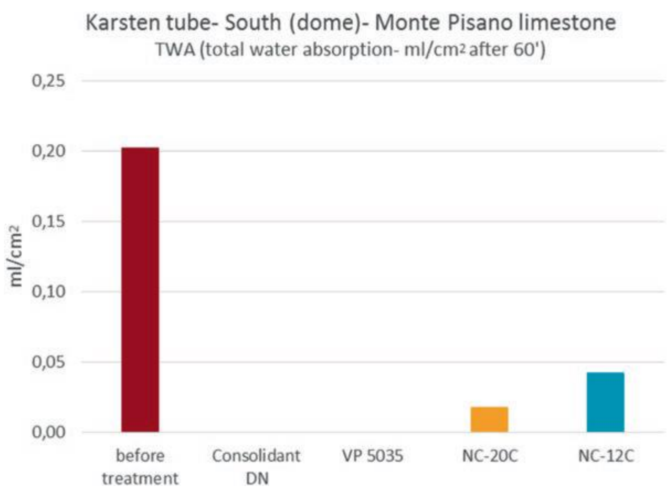
Environmental measurements from October to mid-November, crossed correlated with the days in which the control tests were undertaken

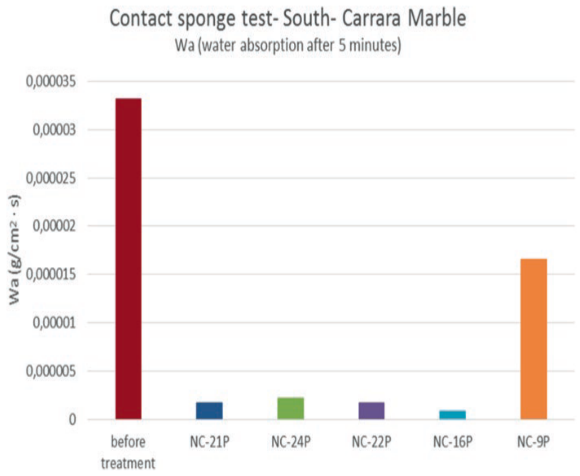


Water absorption before and after the application of consolidant on Carrara marble

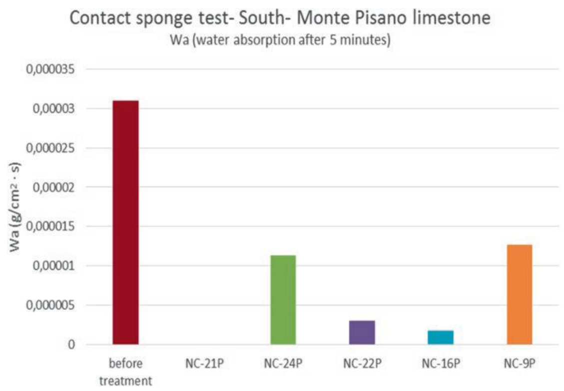
Water absorption before and after the application of consolidant on Monte

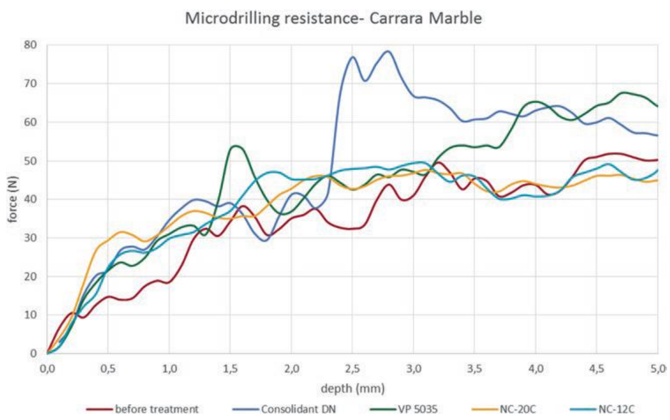






Contact sponge measurement before and after the application of protectives on Carrara marble

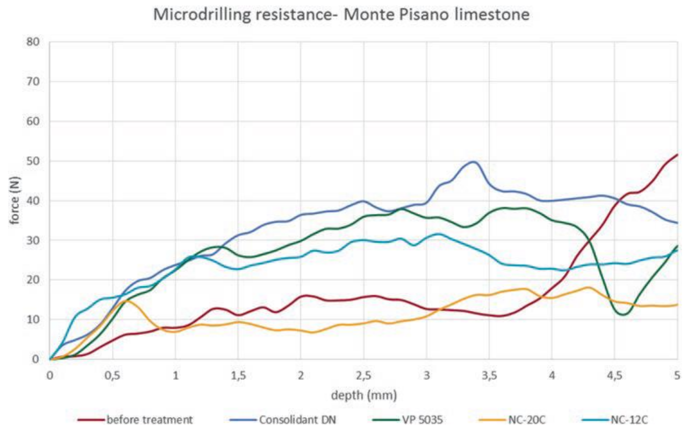




Trend curves of mechanical resistance before and after the application of consolidants on Carrara marble

Contact sponge measurement before and after the application of protectives on Monte Pisano limestone

South - Carrara Marble		
	ΔL	ΔE
NC-21P	-0,85	1,17
NC-24P	-6,68	7,24
NC-22P	0,19	0,20
NC-16P	-2,10	2,71
NC-9P	5,05	7,21



Color measurements on protectives applied on small scale areas.

In red the protectives that brought a visible chromatic change

Trend curves of mechanical resistance before and after the application of consolidants on Monte Pisano limestone

South (dome)- Carrara Marble		
	ΔL	ΔE
Consolidant DN	-1,56	1,73
VP 5035	-1,76	1,77
NC-20C	-1,14	1,14
NC-12C	2,25	2,28

South- Monte Pisano limestone		
	ΔL	ΔE
NC-21P	-1,02	1,19
NC-24P	-0,77	0,80
NC-22P	-2,08	2,19
NC-16P	0,52	3,02
NC-9P	-4,54	4,79

Color measurements on protectives applied on small–scale areas. In red the protectives that brought a visible chromatic change

Color measurements on consolidants applied on small-scale areas. In red are the consolidants that brought a visible chromatic change

South (dome) - Monte Pisano limestone		
	ΔL	ΔE
Consolidant DN	-1,72	1,86
VP 5035	-1,59	2,28
NC-20C	-3,25	3,64
NC-12C	-1,66	5,87

Color measurements on consolidants applied on small scale areas. In red are the consolidants that brought a visible chromatic change

Consolidants Final Results

Consolidants	**1 Week's Time**	**2 Weeks' Time**	**2 Months' Time**	**Colour Compatibility**	**Water Absorption Reduction %**	**Mechanical Resistance Increase (N)**
Consolidant DN	Increase of colour intensity	Increase of colour intensity	Slight Increase of colour intensity	1,80	92%	14,78
VP 5035	Increase of colour intensity	Increase of colour intensity	Slight Increase of colour intensity	2,02	90%	16,78
NC – 20C	Increase of colour intensity Slight change in hue (Yellowish)	Yellowish colour Increase of colour intensity	Increase of colour intensity	2,39	63%	-8,73

NC – 12C	Increase of colour intensity Silica Crystallization on the surface	Silica Crystallization on the surface	Increase of colour intensity	4,07	60%	0,67

Consolidants: final results of the playground

Protectives Final Results

Protectives	**1 Weeks' Time**	**2 Weeks' Time**	**2 Months' Time**	**Colour Compatibility**	**Water Absorption Reduction %**
NC – 21C	Increase of colour intensity	Increase of colour intensity	Slight Increase of colour intensity	1,54	94%
NC – 24C	Slight Increase of colour intensity	-	Slight Increase of colour intensity	4,09	84%
NC – 22C	-	-	-	1,43	84%
NC – 16C	Slight Increase of colour intensity	-	Slight Increase of colour intensity	2,01	84%
NC – 9C	Whitening	Whitening	Whitening	3,87	40%

Protectives: final results of the playground

Conclusion

Based on the preliminary results obtained from the project, several important considerations have emerged. One of the key issues highlighted by the results is the need to better demonstrate the benefits offered by nanotechnology in the preservation and conservation of historical buildings. This includes factors such as suspension stability, low toxicity of the medium (water or alcohol), increased reactivity, improved compatibility with stones, functional properties, and similar porosity to the host stone. It is crucial to find the right balance between incorporating the active principles of the nanotechnology and ensuring the stability of the liquid product.

The significance of this project lies in its potential to provide comprehensive and reliable knowledge on a European scale. This knowledge can support the restoration of historical buildings, guide public and private institutions involved in stone conservation, and assist professionals and companies engaged in the protection of new buildings. The results of this European project aim to bring innovation to the field of technology while rationalizing conservation policies. Ultimately, this will lead to an enhanced understanding of the complex interaction between treatments and stone substrates and establish durability thresholds for these treatments.

Recommendation

Provide Key Tool "Reference" for Restoration and Conservation in Egypt by studying and picking the Optimum nanomaterials according to:

- Lithotypes Classification
- Climatic Classification
- Time Scale
- Environmental Approach

Using nanomaterials to overcome problems facing Heritage Buildings related to both Human Factor and Environmental Effects.

Raise the awareness among Archeologists, Restorers and Architects of the importance of using updated techniques in order to maintain preserving of our Heritage Buildings.

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