Innovation and Resilience in the Redevelopment, Restoration and Digitalisation Strategies of Architectural Heritage

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Abstract. The architectural heritage is the expression of the vast cultural heritage, as a set of cultural and landscape assets, of the different national or international territorialities, which indicates in the connective of the heterogeneous urban, rural and mountain landscape areas, an inestimable value of the monumental historical buildings. The various transformative factors of administrative management and socio-economic cultural type, monitored by quality and compatibility indicators, distinguish different realities over time, in which technological innovations prevail. The objectives are the valorisation and resilience of the architectural heritage at different scales, for the reduction of seismic vulnerability and prevention against natural disasters (floods, erosions, seismic risk, exposure to ultraviolet rays, etc.) and climate crisis, through a model operational that focuses on various innovative strategies that also guarantee an adaptive reuse with a view to sustainability. The intervention criteria on the historical monumental building are according to a project that distinguishes the historical/cultural values with the use of innovative technologies and energy efficiency with the use of innovative materials, for safety needs, fire resistance, integrability, appearance, etc. according to indicators of environmental sustainability and chemical/physical, dimensional, energetic compatibility, etc. with zero environmental impact. Both in line and in cooperation with ICCROM, UNESCO, UNFCCC, Paris Agreement, ICOMOS, New Technology, COP27 Cleantech, etc. The methodological approach is based on phases of documentary collection, mapping, cognitive analysis, cognitive analysis of the architectural heritage privileging the diagnostic aspect, on a meta-project with verification, interdisciplinarity, monitoring and control of the definitive project. Use of innovative smart non-invasive technologies with properties of durability, flexibility, mechanical resistance, thermal conductivity, etc. with nanobiotechnology, innovative materials such as fiberglass mesh and reinforcing bars, on the internal surfaces, socks of artificial micro steel strands for the consolidation and linking between the pre-existing and new walls, of pillars, columns, etc. Use of technologies, local construction techniques and indigenous materials for raw earth buildings, FRCM (Fibre/Fabric Reinforced Cementitious Matrix/Mortar), FRP (Fiber Reinforced Polymer) composites in epoxy or polyester resins with carbon fibers, glass, aramid and boron polymers, for reinforced concrete products, etc.360° video technology, for immersive use both for document management in the archive database and for interactively viewing reconstructed monuments etc., acquisition of 3D models with non-contact 3D scanning technology to preserve and transmit object data in the future. Redevelopment strategies with energy retrofit as part of urban regeneration,

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sustainable architectural restoration, recovery and consolidation also with a view to new digital reality (DR) and virtual reality (VR) IT strategies. Evaluation systems, analysis of degradation and instability with design, bioclimatic choices, etc. The challenge is to pass on to future generations a sustainable architectural heritage as a document of historical, architectural, artistic, archaeological, etc. value. of cultural heritage.

Introduction

The architectural values of the cultural heritage are highlighted in a set of other historical and landscape values through a language praying for authenticity and originality.

Well these represent a set of works of cultural heritage in which man designates his own artisticity and peculiarity with techniques and technologies, to valuable artefacts that indicate the different artistic and historical cultures, in a connective of popular cultures of intrinsic characteristics that settle in a certain territory.

In particular, the architectural value of monuments can suffer over time forms of dispersion of both the image and the material due to various factors which highlight, first of all, environmental pollutants and land degradation due to certain natural causes which slowly influence on the built.

Especially for seismic and flood disasters as well as for natural ventilation in certain territories and marine exhilaration that act over time or suddenly on the architectural heritage in which the image and consistency need to be passed down for its valorisation and historical document.

Therefore numerous organizations aim at this objective in which architectural value and resilience predominates, in the sphere of conservation of the built environment, such as the ICCROM [1] (International Center for the Study of the Preservation and Restoration of Cultural Property), acronym

of the merger of International Center for Conservation and Center of Rome, which is an intergovernmental organization that stimulates scientific research, promotes the restoration and conservation of monuments and all cultural heritage at an international level for the purpose of their valorization, protection and also for sustainable adaptive reuse.

UNESCO [2] (United Nations Educational, Scientific and Cultural Organization), the United Nations organization, also contributes in an international cooperation of peace and security to the protection, protection and identification of the world's cultural heritage, for the valorization and transmission to future generations .

This also happens through new guides and methodological tools for impact assessment on projects and infrastructures in collaboration with the other consultative bodies of the World Heritage Committee, such as ICOMOS [3,4] (International Council on Monuments and Sites) and IUCN (International Union for Conservation of Nature). In fact, among the many works there is the initiative to reconstruct the medieval Medina of Marrakech (Fig.1) in Morocco among the world heritage assets, heavily damaged, like all the other UNESCO sites in Morocco currently at risk, from the natural seismic event of 8 September 2023 which caused a huge disaster of monuments and archaeological sites, etc. but above all of human lives. Therefore, with the same objectives is the ICOMOS (International Council on Monuments and Sites) as a non-governmental organization, which is characterized above all by the promotion of technologies and methodologies for diagnostics and conservation aimed at the redevelopment with valorisation and revitalization of the architectural heritage and sites of historical, artistic and cultural interest.

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Fig.1. Koubba Ba'adiyn, Marrakech-Moroccan Architecture. [5]

The criteria are those of intervention on the built environment, of identification of historical, architectural and cultural values with the use of innovative and efficient technologies and materials, also energetically, for safety, fire resistance, integration, appearance, sustainable and with dimensional compatibility, and above all to zero environmental impact.

Therefore innovation and resilience in architectural heritage, through a methodology of graphic and photographic documentary collection, on-site analysis, etc. cognitive and cognitive analysis favoring diagnostics, to delve into the needs of the restoration of the monument, and in which to identify the architectural and distributional characteristics, analysis of the crack pattern, of an operational model, in which digitalisation becomes an important approach with zero sustainable interventions impact and energy saving and efficiency, assessed on a case-by-case basis, for the purpose of its "recognition" of cultural value as supported by Cesare Brandi in "Theories of restoration" [6] and against climate change as also supported by the 2030 Agenda. Even the same international environmental treaty of Rio de Janeiro in 1992, called the United Nations Framework Convention on Climate Change UNFCCC (United Nations Framework Convention on Climate Change), ratified by the COP (Conference of Parties), like the Paris Agreement of 2015 , to keep the increase in global average temperature below 2°C, while for COP 27 it aims for 1.5°C, etc. for the reduction of greenhouse gases, as it is considered the predominant cause of global warming. Innovative technologies and materials, for the restoration and in particular cases of redevelopment of both historical and modern architectural assets, with their refunctionalization (museums, libraries, legal/educational/administrative units, etc.) which are distinguished case by case, with efficiency energy, represent the intervention criteria on the built environment, for authenticity requirements in the integration of the image, consistency and state of conservation [7] of the architectural work to be handed down, according to a meta-project methodology with potential impact assessment and verification of alternative or mitigation systems for the final project. Use of smart technologies for the restoration and structural consolidation of pre-existing reinforced concrete, 3D models with 3D scanning technology, 360° video technology for immersive use, with DR (digital realities) and VR (virtual realities). New Technology and Cleantech, respectively with artificial intelligence, robotics, etc. with the adoption of durable materials, with chemical-physical compatibility, flexible, reversible, in epoxy or polyester resins with carbon fibres, aramid and boron polymers, FRCM composites, glass, titanium, etc. with innovative products for the structural reinforcement of pre-existing masonry and reinforced concrete buildings. Particular attention is paid in almost all Mediterranean cities to the creation of architecture with raw earth from Italy, Jordan, Morocco, etc. with different construction techniques and mainly the Bisè and the Adobe in which the new strategies aim above all at the adoption of innovative technologies, with the improvement of local materials of the *genius loci,* with new compositions of material mixes and innovative technological intervention devices. For this purpose, the use of clay is increasing, a

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material that is well suited both for the restoration of the historical architectural heritage and for recovery such as the cladding of some walls, for roofs, etc., and in new buildings. Through a practice, first of reconnaissance of the places and then of the object of restoration, or recovery and in some cases of urban regeneration, through cognitive and cognitive investigations with diagnostic instruments, the state of progress of the degradation is known, aimed at a architectural and conservative restoration project, recovery of the pre-existing with revitalization and urban regeneration, through the adoption of a procedural operational model, in which to highlight the technological innovations in the restoration intervention with resilient and sustainable technologies, both environmentally, economically and socially .

Restoration for sustainable practice

The unitary value of the work evident in a monumental asset, as the result of a restoration intervention, represents the integration of an architectural image of the contextualized asset in which the aesthetic and historical instances are intrinsic, indicating the historicity, the artisticity and the philological identity that brings the degraded work back to its original form.

In Italy, according to the Code of Cultural Heritage and Landscape of the Legislative Decree, 22 January 2004, (updated to 01/08/2023) n. 42, art.29, paragraph 4, *" By restoration we mean direct intervention on the asset through a complex of operations aimed at the material integrity and recovery of the asset itself, at the protection and transmission of its cultural values. In the case of real estate located in areas declared to be at seismic risk according to current legislation, the restoration includes structural improvement interventions*" [8].

Therefore within a unitary project of sustainable restoration the aim is pure conservation, even with structural reinforcements, the protection and museum values of liberation, consolidation and differentiated integration, of the historicity and artisticity of the pre-existing work, up to functional adaptation with objectives of valorisation of the assets and also projected various refunctionalisation purposes including scientific/cultural educational, legal/administrative, etc.

To this end, scientific research and new intervention trends with local and international initiatives including UNESCO (United Nations Educational, Scientific and Cultural Organization), etc. they also aim at reconstruction projects, such as for the medieval Medina of Marrakech, and with the advanced WHEAP program (World Heritage Earthen Architecture Programme), for other interventions for raw earth buildings, etc. such as ICCROM, ICOMOS (International Council on Monuments and Sites), IUCN (International Union for Conservation of Nature), etc. which push for the valorization of cultural heritage with sustainable and resilient redevelopment, etc. This is achieved through new technologies and construction techniques with innovative and eco-sustainable materials, at an international level for the restoration of architectural heritage and as in the Mediterranean areas which include those from Europe, North Africa to Western Asia with the Near East, etc. UNESCO ensures, through the World Heritage Center and the Intergovernmental World Heritage Committee (WHC), the implementation of the World Heritage Convention, ratified in 1972 in Paris, which represents the first instrument for safeguarding the World Heritage for transmission to future generations of cultural assets which are important for maintaining solidarity, development of the planet and peace. In particular, cultural assets are recognized by the Committee (representatives of 21 member countries elected by the General Assembly) with Outstanding Universal Value (OUV) (Fig.2) together with the conditions of authenticity and integrity, which are the basis of the World Heritage Convention and all associated activities, including impact assessment. They are included in the WHL World Heritage List (World Heritage List), established by the Convention, corresponding to at least one of the criteria set out in the guidelines, as the assets that constitute it belong to the world population, regardless of the territories in which they are located and well over 1,100 sites worldwide are recognized as World

Heritage Sites. In 2023, "Guidance and Toolkit for Impact Assessment in a World Heritage Context" were published by UNESCO, ICCROM, IUCN.

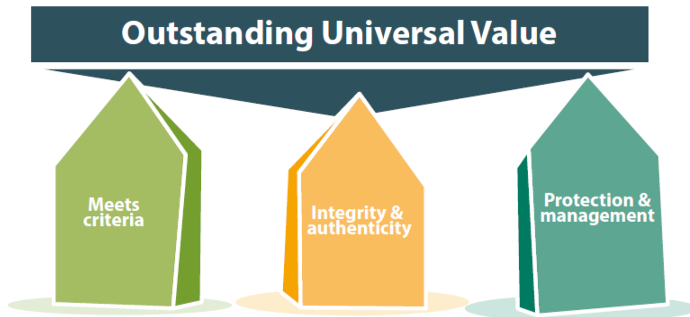

Fig.2. The 'three pillars' of Outstanding Universal Value. [9]

Guide and tools, for project impact assessments, become the reference for achieving damage prevention objectives, and for identifying sustainable operations of places subjected to increasing pressure from development projects both within and around the same sites. The UNESCO guidelines "Operational Guidelines for the Implementation of the World Heritage Convention" Operational Guidelines WHC.23/01 24 September 2023 also represent an important tool mainly for the protection and conservation of global cultural heritage which are periodically updated regarding decisions of the World Heritage Committee [10]. To this end, the restoration needs relating to the architectural heritage are also environmental and contextual and mainly due to climate change, which affect the pre-existing cultural heritage, causing degradation with lesions, microfractures, etc. chemical-environmental, erosion and sometimes irreversible or partially reconstructable damage in historical artefacts, also degradation from natural seismic disruptions, hydrogeological disruptions, anthropic activities and more as among multiple restorations, including that of the church of Santa Maria del Suffragio from 175 in Aquila in Italy, with a neoclassical dome added in the first half of the 19th century, and attributed to Giuseppe Valadier, following the 2009. L'Aquila earthquake, with restoration work completed (Fig.3) (Fig.4), (Fig.5). In this restoration intervention, innovative technologies were applied with anti-seismic reinforcement products of FRMC systems in R.A. fiberglass, alkali resistant with two-component premixed cement mortar.

Certainly each territory is characterized by pre-existing cultural heritage in which the architectural heritage is distinguished by local construction systems and techniques, different technologies and materials for the building typologies, with different intended uses such as residential, tertiary/office, commercial, tourism-receptive, productive, agricultural, etc.

In Italy also under the patronage of the CNR (National Council of Research-Works of Art of Rome and Milan) and of the ICR (Central Institute for Restoration) with the NORMAL Commission (Normalization of Stone Materials) and continuous ongoing research, we have identified unified and specific study methodologies of the alterations of stone materials, with control of the effectiveness of the conservation interventions of the same stone materials of Cultural Heritage in technological innovation and sustainability [13].

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Fig.3. Church of S. Maria del Suffragio, Aquila, Italy. Seismic failure of the dome. [11]

Fig.4. Church of S. Maria del Suffragio, Aquila, Italy- Dome restoration.[12]

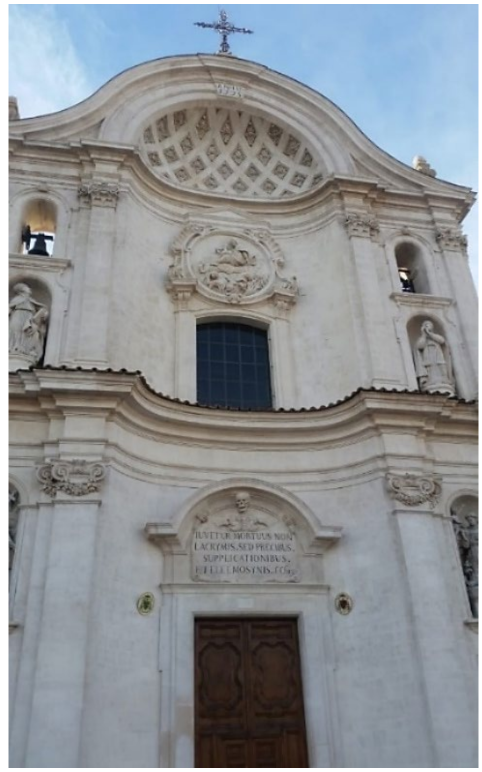

Fig.5.Church of S.Maria del Suffragio, Aquila Italy, Façade restoration with work completed. [12]

Globalization has induced major social and economic changes which, with new technological processes, have influenced the typological evolution in the construction sector, with the use of innovative products. These are adopted both for restoration work in the different typologies of conservative, architectural, scientific, functional, philogological, critical, and reconstruction, redevelopment, recovery, etc. with a view to sustainability and resilience of the works subject to intervention, a programming that requires a unitary project and in which the various specialist skills are coordinated by interfacing on a scientific/operational level. Therefore, we aim for an operational building model in the design process of architectural restoration of the architectural heritage, based on criteria of minimum intervention, which requires an in-depth study of the monument to "know so as not to intervene" so that good diagnostics can avoid invasive interventions, such as in the field of medicine. Even the criterion of reversibility required in the architectural restoration of cultural heritage and in particular of monuments, must potentially give the possibility of removing, exceptionally, any additions, additions or re-integrations, which have occurred over time during conservation interventions and without causing damage to the original monument. These interventions generally refer to gaps in the wall structure integrated with new, durable, eco-compatible and eco-sustainable green building materials, in a dialogue of artistic continuity between old and new, in various techniques that indicate the intervention of a conservative restoration project in the monument , potentially predisposed to future interventions for re-integration.

For this purpose, the reference is also to multiple solutions of integrations or additions to the pre-existing one, such as removable systems placed dry and without wiring, concealed in the walls of buildings, or to covers or roofs with removable frames in a scheduled maintenance project, etc.

The distinguishability criterion is adopted to highlight the pre-existing historical artistic structure from the restoration interventions [14] that have taken place over the years and the adoption of steel and glass indicates the distinction between load-bearing and load-bearing structures, etc. Finally, it is necessary to adopt the compatibility of new construction materials with reference to the chemical-physical one which integrates without damage into the monument. To this end, research advances new sustainable, resilient materials, nanotechnologies and biotechnologies in historic structures such as titanium in the textures of historic walls, the injections of compatible low-carbon and low-cost lime mortars, [15] formulated with high durability, not particularly expensive, appropriately formulated based on the relative functions of the restoration project, replacing traditional nailing systems with reinforced concrete additions, etc.

The partial reconstructions sometimes respect the continuity and assonance of colours, materials, configurations and sometimes continuity with pre-existing construction techniques in the walls, highlighting the innovative quality of the restoration process and in which for structural consolidation, compatible micro pilings and plinth systems are often adopted from which to begin the partial reconstruction. For this purpose, in the thirteenth-century castle of Saliceto in Cuneo, Italy, (Fig.6), the[16] eastern tower known as the technological tower (Fig.7) was rebuilt on its original form, totally destroyed and according to criteria above all of distinguishability in the conservative restoration with adaptive reuse as a new public building, with a steel structure and ventilated walls covered in cedar wood panels, compared to the remaining three towers and the entire monument in load-bearing brick masonry. It contains the new thermal power plant.

Fig.6. Saliceto Castle, Cuneo, Italy. North-East view, restoration with reconstruction of the tower. [16]

Fig.7. Saliceto Castle, Cuneo, Italy: a. East elevation, state of the places, b. Detail of technological tower reconstruction. [16]

Among the conservative architectural restorations, the reconstruction work on the roof of the Gothic cathedral of Notre-Dame in Paris (Fig.8) and the spire, destroyed by fire, are noteworthy. The cathedral was restored in 1844 by the French architect Viollet le Duc, presenting the plan with a central nave divided into three floors, and two side naves, the central one is approximately 37 m wide, and 125 m long, 32 m high. with columns supporting pointed arches on which the hexapartite vaults originate. Today's conservative restoration underway is based on stylistic choices that recall the original project and materials in wood from centuries-old oaks, originating from French forests, with the reuse of the pre-existing iron reinforcements in the cathedral, in types of iron staples on the top walls of the south nave, in a, instead in b, iron braces of the monolithic columns of the nave, in c iron braces in the choir gallery. (Fig.9. a,b,c).

Fig.8. Notre Dame Cathedral, Paris. Restoration work. [17]

Fig.9.Notre Dame Cathedral, Paris Detail of iron staples: a. south nave, b. monolithic columns nave, c. choir stand.[18]

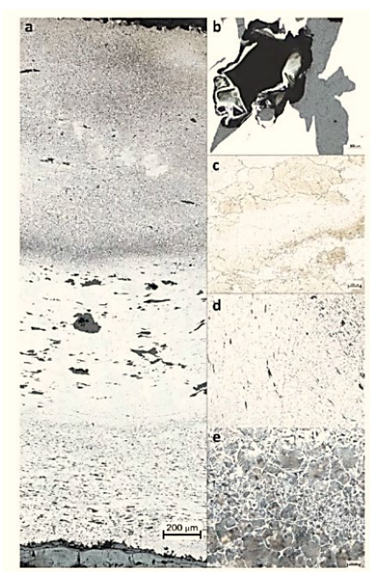

Fig.10. Notre Dame Cathedral, Paris. Micrograph tests, (a, b, c, d, e). [18]

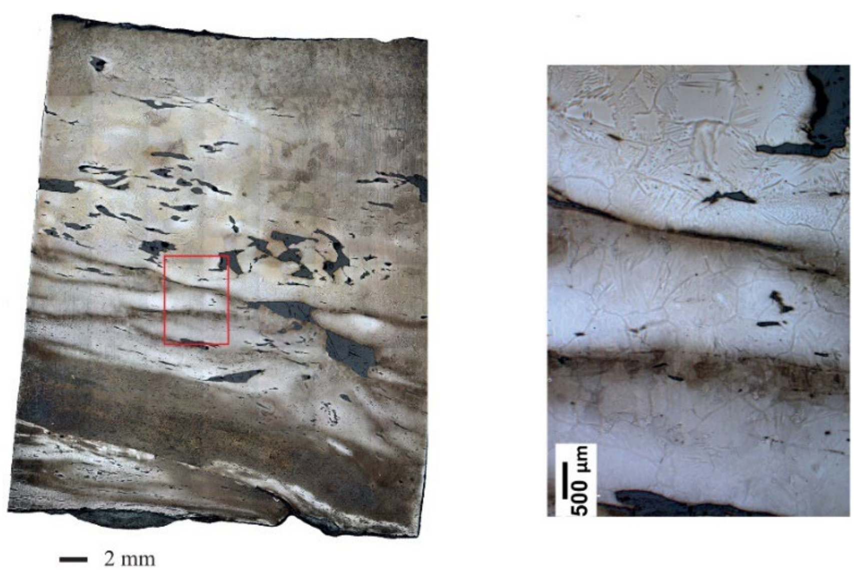

Fig.11. Notre Dame Cathedral, Paris. Oberhoffer on sample NN9-T with mesoscopic microscopic changes in P content, with highrate in lighter areas. [18]

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There are micrograph tests, (Fig.10) a. Micrograph of NS8-L solder with different grades of ferrous alloys (from bottom to top, small SI ferrite, large SI ferrite, carburized ferrite-pearlite). b. S

lag inclusion and porosity (NS106-T1). c. Ghost structure and different grain size of ferrite (NS8-L), d. Lightly carburized area with Widmanstätten ferrite and small SI (NS106T1), e. Area cemented with pearlite and ferrite from Widmanstätten (TRIB01S). Instead mesoscopic and microscopic variations result with Oberhoffer on the NN9-T sample (Fig.11).

The reconstruction is based on innovative digitalisation criteria with 3D model by the French CNR in collaboration with the French Ministry of Culture, based mainly on the Aïoli platform which has the monument, like all heritage assets, at the center of the design process for its conservation [19]. This platform is based on the photogrammetric technique, useful for the 3D model for image purposes, and on the cloud for the processing and sharing of collected data, therefore also based on documentary and photographic collections and digitization with 3D laser scanners, creating the interface between the artefact, object of restoration, and the documentation produced, in a sort of multi-temporal database analysis which also provides follow-up of the degradation and state of conservation.

For conservation techniques, reinforced concrete castings are also adopted in the internal parts of the degraded walls leaving the visibility of the envelope, on the outside with the previous texture, simple injections of lime mortar or "sew-unseed" operations or the use of titanium, which is more compatible with historic walls than many other materials, etc. with refunctionalization and conservation of monuments and low impact, sustainability and resilience objectives in a development of different phases of a unitary integrated project. The criteria are above all safety needs, visual well-being, usability, adaptive reuse, etc. with requirements for fire resistance, demolition, replaceability, etc. for technological quality in restorative practice.

The methodologies consist of preliminary cognitive investigations of the work subject to intervention, on the places and the territorial and urban context with mapping, documentary collection, analysis of constraints, diagnostics, state of conservation, the state of fact and previous interventions. This occurs through an archival documentary collection, with a phase of reading and graphic and photographic survey of the monument, according to its contextual complexity, its intrinsic values as well as material, artistic, cultural and to pass on its conservation. Furthermore, a subsequent descriptive and cognitive analysis is followed, at a methodological level, by planning for a feasibility study with technical requirements, objectives, performance checks, comparison, figures involved, shipbuilding, etc. and then the design one, preceded by a meta-project, as an organization that identifies technological and spatial criteria and requirements, in order to have a variety of design choices including technological, typological, organisational, spatial, dimensional ones, etc.

The subsequent design phase with intervention strategies is divided into different phases with the adoption of innovative technologies and new materials, as established by the Restoration Charters from that of Athens in 1931 to that of Krakow in 2000, including the three Italian Charters, that of Amsterdam and Washington, etc. and the typological choices of the intervention are defined with a network of operational figures involved, a brief in the preliminary, definitive and executive design phases, execution, testing with checks and control, retrocommissioning, certification systems, etc.

Finally, management with monitoring of intelligent systems for energy and electrical management and control with intelligent technologies, safety, security, maintenance, control of internal pollution levels, checks with blower door tests, etc. [20].

Furthermore, according to its typological and techno-constructive characteristics, its chromatic, spatial, decorative, plastic, urban and landscape qualities and what it has affected the monument over time, anthropic activity with architecture, painting, with the photogrammetric for a BIM

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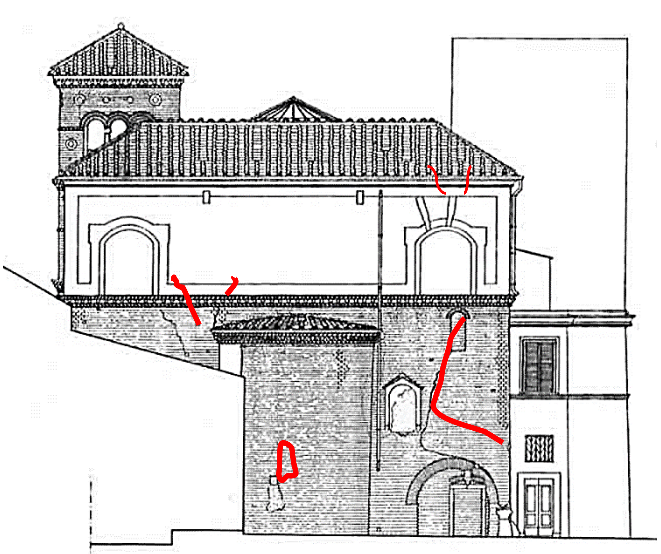
model we move on to the non-destructive diagnostic phase of the damage and then make design choices for the restoration intervention and in which the critical sense of the specialist is highlighted, also with a view to adaptive reuse and valorisation of the monument as well as historical and artistic, for the purposes of transmitting its cultural values, for the good of the community and future generations. The damage that leads to consequences in the architectural heritage is distinguished by its many and different causes, including the load of the building itself, the action of the wind, thermal oscillations, etc. for which the global warming of the earth is at global level, as referred to by the international associations and mentioned above, by the Paris Agreement of 2015, to keep the increase in the average global temperature below 2°C, for COP 27 aiming for 1.5°C, etc. Furthermore, they affect the degradation of cultural heritage, natural seismic action, biological agents, weeds, alluvial rains, fires, floods, the vulnerability of the territory to natural phenomena, volcanic eruptions, [21] diffused humidity (from environmental causes, from capillary rising, from infiltrations, from run-off, from crumbling fixtures, etc.), with manifestations on the plaster of efflorescence, swelling, crusts, mould, different types of detachment, gaps in the surface layers, resulting in internal structural alterations and with external lesions, and on the same materials, in sight, with continuous superficial or internal lesions, lesions of architraves in brick walls, etc. In this sector, the scientific research by universities, institutions, etc. is fundamental in an interdisciplinarity of skills and interventions for the heritage of cultural heritage in order to pass on the historical, architectural, environmental and landscape heritage to future generations.



Church of S. Maria della Luce, Trastevere, Rome, Italy: Fig.12. Degradation phenomena on load-bearing brick masonry. [22]

Fig.13, a, b. Details of damage on the façade. [23]

For this purpose, the image in figure12, of a graphic highlights the micro-cracks on the load-bearing masonry in *opus testaceum* with cracks on the arches and architrave in piperine marble on the western apse of the Catholic church of S. Maria della Luce in Trastevere, Rome, built by the roman architect Gabriele Valvassori in 1730 with late Baroque transformations, on a pre-existing medieval early christian plan. This work carried out as part of scientific research and study for a conservative architectural restoration project of the entire church, was the subject of a specialist thesis at the Faculty of Architecture, Sapienza University of Rome, and subsequently reported in a publication.

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Finally, among the further alterations in the architectural artefact, subject to restoration, the effects of condensation due to access of water, of structural voids with porosity and fractures are listed, compromising the mechanical properties and chemical composition of the construction materials of which it is made, and more. Therefore causes that can alter the chemical-physical and mechanical characteristics of the construction components and causing in the monuments, deterioration of the surfaces, load-bearing structures with total or partial structural failures, erosions with removal of materials from the surfaces due to further environmental, mechanical and chemical-physical phenomena, internal alveolizations with micro cavities, decohesion between the materials and components of the structure increasing their porosity [23].

In fact, an advancement of the decohesion causes the digregation of the materials of which the monument to be restored is composed with detachment of plaster even on the facade. Therefore, we aim for a practice of structural consolidation in the unitary architectural restoration project with a master plan and interdisciplinary network of figures involved, with a decisive methodological choice that adopts non-invasive materials and techniques that bring the historical-artistic artefact back to its identity unity. In fact, since the problems resulting from the degradation of monuments [24] affect building typologies with different intended uses, for each of them, in a state of degradation, action is possibly taken with maintenance, prevention and protection interventions, with integration or reconstruction of the gaps within a framework of cracks in the facades, with internal and external paintings that reflect the pre-existing colors with innovative green building materials, with consolidation in the load-bearing structures and innovative technological systems and plant restoration of the entire envelope.


a


b

Church of S. Maria della Luce, Trastevere, Rome, Italy Details (a, b):
Fig.14. a. Structural lesions. [23] *Fig.15. b. Structural lesions with gaps in concrete. [23]*

For example, lighting such as heating, security systems, access control, video surveillance, alarm and fire prevention systems, etc. of monuments and buildings of worship, the latter entrusted, in Italy, to the FEC (Fondo Edifici di Culto) and managed by the Ministry of the Interior, with objectives mainly for the restoration, valorisation, protection, seismic safety and promotion , represent a particular complexity for their implementation and wiring, supported in part by projects

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integrated with artificial intelligence and smart building management systems with BAS and BEMS compared to the pre-existing architectural structures, having to reconcile the needs of adaptation to technical regulations, those of distribution in the product.

Therefore, a careful study is required, preceded by a stylistic and historical documentary analysis, on the state of structural degradation and architectural characteristics, aimed at integrating the architectural image with new materials, construction techniques and innovative technologies, such as reading and testimony of the pre-existences of the document, prepared for future restoration interventions with a new design and innovative technologies, with further museum purposes and enhancement of the architectural consistency of the monument [25], frescoes, sculptures, paintings, etc. For this purpose, digitalisation also represents an innovative technology in the practice of the restoration project on which the possible system integrations are based and with the museumisation and other uses of the restoration work which is well prepared for future work.

Innovative strategies in the resilient restoration and redevelopment process

Resilience in the architectural heritage, mainly made up of inorganic materials and characterized by their own chemical constitution, porosity, hardness, the PH represents that ability to materially resist any anthropic, traumatic and environmental event, absorbing energy depending on the different reactions in the material , of an elastic/plastic type and to return to its initial state after the trauma.

In the restoration, recovery and redevelopment of cultural heritage, this ability of the material to resist traumatic, environmental and temporal/anthropic actions and to adapt to changes is assisted above all by new sustainable biotechnologies, which through the use of microorganisms or vital bacteria counteract the deterioration of matter. It is highlighted by the formation of microbial patinas on the surfaces of monuments with losses both on the surfaces, in the casing and in the structural part with sometimes irreversible damage and not yet having reference limit values of polluting effect to which the entire historical and artistic heritage is exposed, both outdoors and indoors.

The diagnostic phase, a principle that arose in Italy from the 1972 Restoration Charter, [26] represents the preliminary activity of restoration investigations of the monument with archaeometric tests of different types, instrumental analyzes of low invasive typologies proceeding from multi/interdisciplinary activities with acquisition of archival, contextual, historical, techno/constructive data and materials on the built heritage, with survey of multiple typologies digitized from HBIM up to 3D laser scans, photogrammetry, and more, restitution and graphic representation, from in situ investigations, from foundations to vertical and horizontal structures. In fact, site analysis involves checking the stability of any slopes with inclinometers, piezometers, etc. with geotechnical, penetrometric, scissometric analyses, seismic and sonic methods, and more, and with laboratory tests for the classification of soils and identification of their mechanical characteristics. For vertical structures including walls, columns and pillars, different types of investigations follow, such as laboratory ones with possible tests directly on samples of stone material (crystalline in nature), for the state of absorption by capillarity BS EN 1925:1999, for condensation, run-off, rainwater, freeze-thaw, with resistance to degradation. Non-invasive microscopic investigations, via optical microscope, scanning electron microscopy (SEM-EDS) (Fig.16) with technologies compliant with ISO measurement methods, which instead of light use electrons to create morphological images of the surface and record physical-microstructural alterations which, integrated with the EDS probe, also performs high-resolution elementary chemical analysis for the composition of stone materials, with the analysis of the fluorescence X-rays emitted from the areas irradiated by the beam. SEM EDS technology allows you to analyze the degradation with possible corrosive phenomena even of metallic materials typically chlorines

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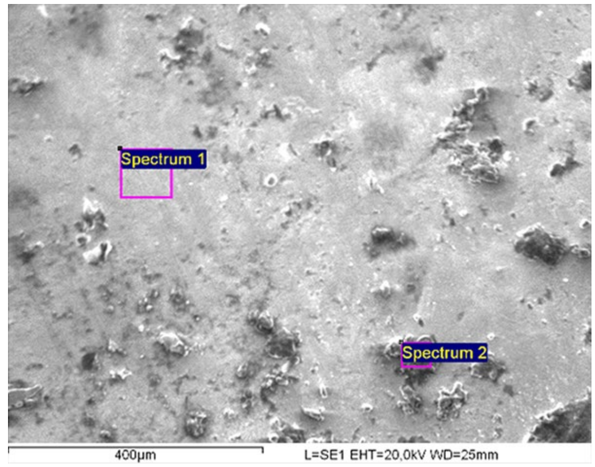
and sulfur from inorganic acids, or from anthropic phenomena, marine exposures, industrial sites, and more, indicating the type of intergranular corrosion, pit corrosion, with EDS microprobe.

The example of EDS analysis- Electrical contact surface coated in gold and with oxidation - presence of contamination from manipulation (Fig. 16. a, b).

a



b

Fig. 16. Scanning electron microscopy. Morphological and dimensional analysis of the structure of phosphating crystals: a. SEM EDS unit details sample, b. Chemical composition of the coating. The image indicates the correct phosphating application required, such as the drawing. [27]

Furthermore, X-ray diffraction identifies the composition of stone materials with a state of chemical alteration with efflorescence and surface deposits, calcium oxalate patinas, black crusts, etc. They are followed by other qualitative analyzes with thermography, ultrasonic, skelometric and dynamic tests with injectability tests, magnetometry, and endoscopic tests.

Among these is an endoscopy which, through the endoscope, a flexible tube probe, made of metal called baroscope, made of optical fibers called fiberscope, equipped at both ends with an image camera and at the other with a light source with lenses and mirror, is capable of inspecting the state of conservation of wooden structures or other materials, false ceilings, inaccessible structures, wired systems, cavities, etc.

This is followed by investigations into plant or animal biodetriment which causes chemical, physical and mechanical deterioration, the sclerometric investigation with a steel impact mass adopted for testing the resistance of concrete and quality deficiencies in the masonry.

The thermography technique which instead operates in the band of infrared electromagnetic radiation, is developed through an infrared video camera which records the emissivity of the materials, returning the heat produced through a mapping reworked by a PC in different colours, of thermal dispersions, depending on the surface temperatures of the materials, of walls with different architectural consistencies, different materials adopted, cavities, infills, lines of thermal bridges, demarcation of rising capillary humidity, etc.

Particular interest is also indicated by the micropulse, high-energy LIDAR (Light Detection and Ranging or Laser Imaging Detection and Ranging) fluorescence technique for laser surveying and restitution of 3D/BIM models, sustainable and innovative for the survey of biodeterioration and as a combination of biotechnological technique and physical technique. It also works for quick screening of monuments. Furthermore, the Laser scanner survey to carry out precise and high-performance three-dimensional architectural surveys.

The ultrasonic survey, on the other hand, based on the identification of the speed of wave propagation, is equipped with a detection unit connected to emitting and receiving piezoelectric

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probes, which analyze the mechanical characteristics of the components in masonry, steel, wood, stone, concrete, etc., identifying the stiffness and mechanical resistance of the materials.

Moisture content analyzes are carried out using weight, resistive and capacitive electrical measurements, with calcium carbide analysis. Among the periodic analyses, deformometric readings and structural monitoring are integrated with intelligent wireless sensor technologies, sensor technologies such as SMOOTH, MEMS [28] for intelligent data return, and more. For horizontal structures with vaults and arches, theoretical analyzes with finite element modeling are adopted, with stability checks of load tests on the horizontals and verification of the chains.

For the control and management of safety, fire prevention and air conditioning systems, for safety, scheduled maintenance, structural and environmental monitoring, archiving, non-invasive, which excludes the wiring of electrical wires, and becomes necessary, above all for maintenance, digitalisation with ICT systems, is favoured, detection technologies, drones, satellite, aerial and terrestrial data are adopted in which the technologies are highlighted digital.

Also of importance is the 3D scanning technology for conservation and restoration, for the purposes of monitoring any structural or natural disruptions, erosion, for scheduled maintenance, which is carried out with three-dimensional acquisition of the object of investigation using a structured light or triangulation scanner.

This sustainable, non-invasive scanning operation, which returns a three-dimensional digital model reworked with software, occurs safely for the operators and without contact with the object of investigation, monument or otherwise, preserving it for future generations.

To this end, through HBIM (Heritage Building Information Modeling) for the management, structural monitoring and safety of cultural assets at seismic and hydrogeological risk, etc. or already damaged, for scheduled maintenance, BIM models can be obtained with faithful three-dimensional restitution of the pre-existing one, including the construction systems adopted, the materials, the geometric data of buildings damaged by the earthquake, with a database that can be integrated, updated and replaced depending on the variables received.

Satellite interferometry also allows you to monitor the structural deformations and instability of buildings at risk of seismic, hydrogeological, erosion, etc. and has been used for the 400 European UNESCO sites, such as the Colosseum in Rome (Fig. 17, Fig. 18)) with PROTHEGO (Protection of European Cultural Heritage from GeO-hazards) in addition to the European JPICH PROTHEGO project, for Pompeii, in the center of Rome, etc.

Furthermore, we resort to the use of wireless sensor networks, various intelligent technologies such as BOX-IO etc., on an IoT platform and data analysis, and a web platform and cloud space, which allow us to monitor humidity and temperature levels in a interoperability of eco-systems. For non-invasive structural monitoring, crack meters are adopted in multiple interventions worldwide and as in the Flavian Amphitheater in the archaeological park of the Colosseum in Rome where digitalized surveys with 3D laser scanners have been started (Fig.19,a,b,c) , in which the monitoring system is made up of the Sypeah web platform (System for the Protection and Education of Archaeological Heritage) created in collaboration with the ASI (Italian Space Agency) initiatives of the Italian national body MIBAC of the Ministry of Culture, for a informative webGIS for both monitoring and management and scheduled maintenance, in a collaboration project with research institutions and universities [29]. Also the IBC (Institute for Artistic, Cultural and Natural Heritage) and CNR-ISAC, adheres to these initiatives for the monitoring and management of cultural heritage. In monitoring systems with the crack meter instrument, the possible evolution of crack displacements and instability, etc. is detected. indicating over time, the variation in distance between two initial points of the disconnection, lesion, and more.

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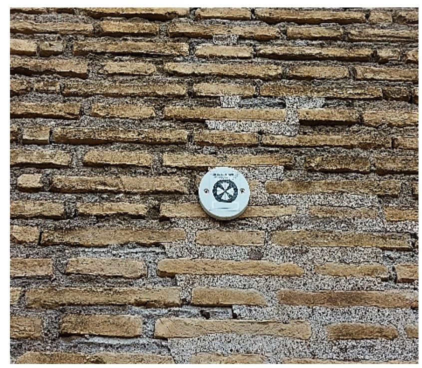
A multi-probe triaxial tiltometer and accelerometer of the monitoring system are connected to analogue communication nodes, consisting of wireless sensors that can be managed remotely, through a Cloud platform with information directly on the online 3D model, about the structures, environmental findings, and more.

Flavian Amphitheater-Colosseum in Rome, Italy :

Fig.17. Perspective view. [30] *Fig.18. Cavea with new restorations. [30]*



a b c

Flavian Amphitheater-Colosseum in Rome, Italy :

Fig.19 (a, b, c) - a. Crack meter on masonry cracks, b. Crack meter detail, c. Geogrà digital system. [30]

These are efficient systems both for monumental, archaeological, museum complexes, and more, in which advantages of process efficiency with modularity of services are distinguished, with a view to improving and optimizing resources, accessibility, security, interoperability of services and between stakeholders and processes.

Therefore eco-sustainable wireless sensors in an integrated management for maintenance, monitoring, access control, smoke and fire detection, etc., also with BMS automation systems for plant monitoring, with a guarantee of using resources more responsibly, with energy efficiency and low consumption, for cultural heritage and in which the architectural heritage demonstrates the quality of the interventions, for the smart and anti-seismic refunctionalization of historic buildings into museums, within an urban regeneration with redevelopment, reuse and valorization of the contextualized asset. Also for user visualization, in a multidisciplinary approach for the restoration, conservation and redevelopment of historic buildings into museum units, with access control, like the museum complexes themselves, the use of digital technologies, in a digital reality (DR), supported by technical means, create a VR virtual reality in which to have an interactive global vision, with the immersive effect of the user's presence (Fig .20, a,b), using 360° video technology. In fact, it is possible to have a vision of closed historical archives, or the reconstruction of historical monuments, finds, through a mouse or keyboard of a personal computer using and connecting to a tablet, smartphone, or to a PC or independently without cable, and adopting, in combination, both video/game and metaverse VR viewers, or alternatively, using a smartphone application, for viewing the 360° video. AR viewers, on the other hand, use digital technologies, through an AR app, in which reality is "augmented" overlaid by digital information, such as images, texts, etc., using smartphone or tablet screens and is a technology used in many museums for an immersive experience of augmented reality through digital screens, during exhibitions, events, and more, as well as the recontextualization of historical, archaeological, etc. objects. So by inserting, for example, a Smartguide on your smartphone, for visits, tours, events, you have an interactive experience with an augmented reality visualization.

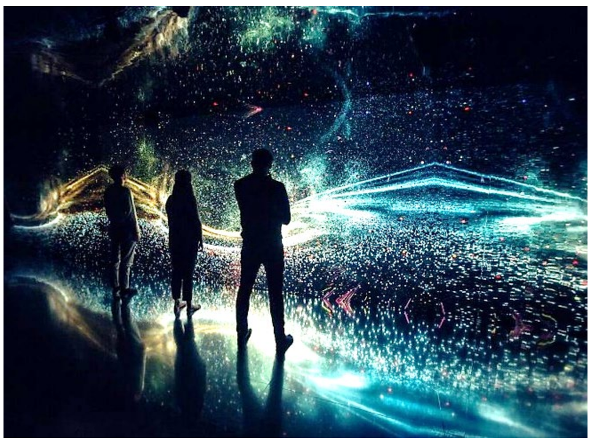


Fig.20 (a,b) : a b

a. Nxt Museum, Amsterdam.Immersive Museum, b. Batllò house, Barcelona. Augmented Reality.

[31] [32]

In a multidisciplinary and innovative approach also with the contribution of digital technologies for cultural heritage, with innovation, museumisation and archaeometry [33], restoration of the architectural heritage, whose project, in the different phases of the building process, aims at interventions resilient with sustainable biotechnologies, innovative strategies with eco-compatible composite materials, etc. in all types of interventions both on wall surfaces, in structures and in some cases in foundations with sustainable nanometric consolidants and protectors, self-cleaning products based on titanium dioxide for concrete of historic buildings, etc. From non-invasive investigations with innovative diagnostic tools and from the activity of interdisciplinary skills that contribute to the identification of damage, degradation phenomena are detected, generated by various main causes (humidity, hydrogeological seismic instability, erosion), both on surfaces and in structures related to contextual and environmental factors and detected above all by the presence of biodeteriogens which initially indicate an effect of aesthetic deterioration on the surfaces. Although it may be found that biopatines are sometimes linked to stone substrates and particular environmental conditions, such as its wavelength, electromagnetic waves of light, which interact with the material, with absorption, reflection, diffraction, and more.

Basically, degradation is indicated as biodeterioration which is distinguished both by the physical/chemical properties of the material of which the restoration work is made and by the environment in which it is contextualized and is caused by microscopic living organisms, such as algae, fungi, bacteria, and more, and those visible such as animals, plants, fungi and higher algae which exert a physical and chemical action on monuments, historical artefacts and in general in building structures. Some examples of physical deterioration are indicated by the phenomenon of efflorescence and subefflorescence with salts depositing relatively on the external and internal surfaces and depending on the porosity of the stone, while the freezing/thawing or crystallization of salts is frequent in climates with a high rate of air pollution and cold/humid/rainy ones, while in the warm, less polluted ones the monuments show the presence of biodeteriogens. They produce damage and also waste in the environment, depositing themselves on the stone artefact, and manifesting themselves, albeit slowly over time, in the form of patina, crusts or patches and also producing CO2 in the environment and the set of all the communities that colonize the substrate stone manifest themselves in the form of biofilm, that is an biological structure of microorganisms with a mucilaginous matrix, of 14 polysaccharides (extracellular polymeric substance EPS).

Therefore, in stone artefacts of an organic nature, various phenomena occur such as deformation and swelling which alter the original shape, or phenomena of erosion, exfoliation, gaps, flaking, with loss of material, also surface phenomena with deposit of patina, and other things that overlap with the material, deforming its image. The degradation distinguished into physical, chemical, biological and anthropic has various causes that determine it. In particular, biodeterioration manifests itself both with the physical appearance, through mechanical disintegration (in connections, on the surface, in porosities, an exerted and induced by the pressure of living things (roots, weeds, fungi, microorganisms, and more), which with the chemical aspect due to the exchange of molecules between stone materials and living beings, a less detectable but documented aspect. The two aspects trigger a degradation process with waste, chelating substances, acids which break down the stone material, releasing oxides, salts, etc. nourishing microorganisms and plants that increase the colonization of living things if the artefacts have been covered with polymers, organic materials, guano. For this purpose, lactic acid, deriving from the fermentation of corn, a natural source, was used to obtain a polymer, considered a biodegradable product by the FDA-USA (Federal Drug Administration), easily enamellable, non-toxic, and as a compound of a metal to obtain a plastic material to be used for the protection and conservation of the stone surfaces of historic buildings and all other cultural heritage. It is necessary to prevent biocolonization, so among the innovative products for the conservation of surfaces, which interact less with the environment, we focus on resilient nanocomposites based on TiO2 titanium dioxide nanoparticles which have the ability to give, to stone surfaces , hydrophobic, self-cleaning properties, and inhibit biomass and biocides, photocatalic with respect to pollutants. They are anti-graffiti and water-repellent, while still remaining permeable to water vapour, de-polluting and anti-fouling, durable and removable without removing stone material and do not alter the colour. For this purpose, nanoparticles (SiO_2, TiO_2, Al_2O_3, SnO_2) in polymeric matrices are adopted. Furthermore, adoption of inorganic composite materials of calcium hydroxide for the structural consolidation of carbonate stones, to inorganic silicon-based composites used both for the consolidation and for the protection of siliceous and carbonate stones. Hybrid products based on tetraethylorthosilicate (TEOS), polymers used in the pre-treatment of cleaning as a grafting agent for better adhesion, avoiding infiltration into the pores of the substrate, and nanotechnologies are also effective for both protection and conservation. NA_TiO_2 and SiO_2-NA_TiO_2.

To eliminate microorganisms or slow down their formation, indirect methodologies are adopted for phototrophic microorganisms (sources of light, humidity, nutritional organisms, dirt, dust, and more) which are then followed by direct such as mechanical methodologies. In fact, mechanical, chemical or mixed and physical methods are adopted to remove biofilms, with high and low pressure washing, low pressure water sprays, and with recourse for the former, to the use of scalpels and spatulas, sponges and brushes, pressure guns, scrapers, sleeve/pump/nozzles, jos and rotec systems, microsandblasting, microaspirators, low and high pressure washing. While for the latter there are compress swabs (compresses with ammonium carbonate and adsorbent clays, etc.), physical/mechanical (cellulose pulp/adsorbent clays, gauze, water and more), enzymes, finally the physical ones with laser and ultrasound. Among the many examples we report the removal of microbial biofilms from the stucco ed Roman tuff masonry from the Domus Aurea on the Palatine Hill in Rome, with biocides based on a mix of essential oils (6.1% - v/v) phytoderivative compounds- lavender, white thyme, wild oregano, liquorice extract, for example in 5 liters of water, etc. with the presence of phototrophic biofilms present in the octagonal room and on the intrados of the surface of the stucco-frescoed vault (Research project with ENEA Casaccia, Superintendence of the Archaeological Park of the Colosseum and restorers)[34]. While for the restoration, conservation, restoration and redevelopment of raw earth buildings, research advances with technological innovations that aim to improve materials together with traditional techniques projected towards engineering and innovation with new systems. Therefore innovation for raw earth constructions in which about a third of the world population lives and present in many mediterranean civilizations. In fact they are also widespread in much of Eastern Europe, both in rural and urban contexts, such as the rural towns of central Spain, in Irish cottages, fortified buildings in the Iberian peninsula, the half-timbered buildings of France, of Germany with sustainable buildings of fachwerk construction systems, with wooden load-bearing structures, visible in the facades and filled with clay mixed with straw, terracotta bricks, types of stone, wooden boards. Raw earth buildings are also widespread in Italy (Lombardy, Sardinia, Calabria, Macerata, Ferrara, Chieti, Basilicata, Abruzzo, etc.), as in Morocco, Jordan, Iran, Afghanistan, Yemen, and are adopted for the restoration of buildings multi-storey with decorated facades, vault and dome systems, retaining walls, and more, with sustainable raw earth materials and local construction techniques.

In fact, for the construction of buildings with monolithic, load-bearing walls and with great thermal inertia, different construction techniques are distinguished in raw earth, including *façonage*, for hand-modelled walls, *Adobe* with clay and sand with shredded straw, *Mud , Brick and Toub*, for masonry with block typologies modeled by hand or in wooden molds which can be plastered and stuccoed, the *Cob,* suitable for the integration of architectural details and tested with 3D printing, *Wellerbau, Bauge,* for stacked and compacted masonry. Among the latter, Superadobe or Earthbags is also used, a construction technique that uses polypropylene or jute bags, stacked and compact and held by barbed wire between the various layers in elevation, making it suitable for walls in areas with high seismic risk. The walls created with *Pisé* and *Rammed Earth* techniques, with innovative design and engineering of the formwork, mechanical compaction of the installation, etc. *Tapia*, *Taipa*, *Taipa De Pilão*, *Taipa* are characterized by rammed earth, composed of earth from the soil, below 50 cm in depth, whereby the organic component is eliminated, mixed with water and fibre, inside wooden formwork. These raw earth typologies (Fig.21. a, b), which have performed in the most disparate geographical and climatic contexts and whose construction durability is made possible by the cohesive capacity, resistance and plasticity of the clay, contained in the interior of the earth grain size, they are eco-sustainable, efficient, improving the internal microclimate, reversible and resilient, with acoustic insulating power. They are eco-sustainable, energy saving with approximately 90% using raw earth blocks compared to fired ones, but they may encounter some construction defects such as staggering of the joints between the blocks, roofing beams that unload directly onto the underlying masonry, without the sleeper which allows for a distribution of loads, the lack of a keystone in the arches which become thrusting causing instability in the masonry itself, etc. Or the recess that is formed by the different thickness of the adobe wall, which rest on a foundation or base in stone available locally and laid dry and are walled with earth mortars, the wider it generates in the first row of the wall ashlars, humidity with corrosive phenomena and caused by the stagnation of rainwater. Furthermore, unsuitable connections between perimeter walls with partitions and with corners tend to behave like single, unconnected walls with precarious static suitability. Usually for each row of the *Pisè* a connection is created by staggering the formwork with respect to the underlying level. Furthermore, other alterations may be caused by the precarious construction of the eaves and the descendant on the wall, which creates water infiltrations with washout and consequent loss of material, or foundations unsuitable for limiting the capillary rise of water, defects in the construction technique such as for example the poor performance of palm wood with related failures and settlements in the masonry, as well as structural alterations caused by environmental factors, etc. and disruptions associated with natural seismic causes.

From a bottom layer of local stone of no less than 60 cm, which varies depending on the building typology, in an excavation usually about 50 cm deep compared to the walking surface, Pisè walls are raised with an inter-storey height of 2.5 m to 5 m, aligning compatibly with the rows of Pisè blocks, with a thickness of approximately 30-40 cm for the houses called *dâr*, up to three floors. However, for taller buildings, such as the *Kasbahs*, the thickness of the Pisè increases up to 60-100 cm, especially in the cantonal ones, those with greater thickness are evident which sometimes reach 1m, and for the better static stability, before casting in formwork, layers of stone are accommodated. Finally, we also include the heights of the buildings which do not always have dimensional compatibility with the bases, as they are sometimes very high compared to them. In the Draa valley (Fig.22) there are more than 300 ksurs and kasbahs from the 15th century. with the most famous fortifications including Amezrou, Tamnougalt, El Caid Ouslim, Ait Hammou Ousaid and Touririt, built in defense of the Amazigh settlements from attacks by nomadic Amazigh tribes, and which stand out among the most important of the historical architectural heritage of earthen buildings raw. Adobe, which is made with blocks and bedding mortar of a mixture of earth, water and straw, laid only in the horizontal joints of 2-4 cm, for transversal ventilation, is usually adopted for the upper floors, with thicknesses that they vary from 40, 50 or 60 cm and for perimeter walls and to support architraves, wooden floors, etc. or to create columns and walls in the patio and on which decorations and architectural details are created.

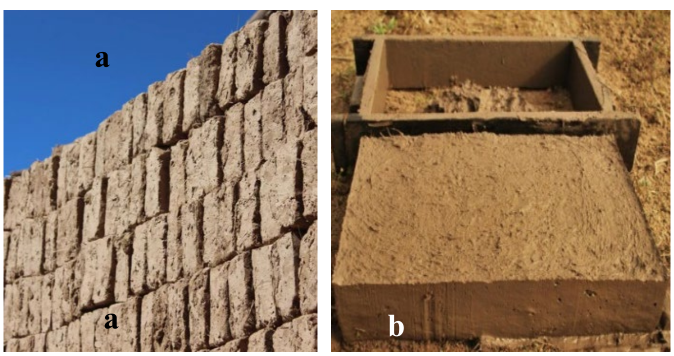


Fig.21. Raw earth constructions: a. Adobe techniques, b. Pisè [35]

Fig.22. Morocco, Draa valley [36]

The new strategies aim to improve interventions in these buildings with a strong state of deterioration of facades with compensation of the gaps, and partially or totally destroyed with the integration or reconstruction of bio-sustainable architectures, through cognitive investigations, up to innovative techniques with the use of energy renewable, suitable reversible materials, and mixtures reinforced with the use of clay, plastic and resilient material, making use of new industrialized technologies for their production, improving the stability and cohesion of the raw earth for the load-bearing structures also susceptible to erosion due to rising humidity, winds, rain, etc.

The methodology of restoration intervention on these construction types is mainly based on scheduled maintenance with continuous renovations and restorations, which, with the help of more innovative interventions, could improve the quality of the earthen artefact with durability and resilience. Therefore the research aims to improve construction techniques on site with the innovation and regeneration of construction materials improved and reinforced by chemical stabilizers such as metakaolin, lime, additives with straw, succulents, etc. for flocculation, a phase immediately following coagulation and as a chemical-physical process that favors the sedimentation of the solid parts in the colloids. In fact, in colloidal solutions, the dispersed solid particles present, on their surface, charges of the same sign which prevent their agglomeration, then there is the greater workability of the material, also in order to be able to be used as a consolidant for gaps in historical buildings architectural, integrating the color, verifying the influence of environmental and landscape parameters, such as in marine and desert areas, on the innovative products of reinforced mixtures, as per common research with bilateral agreements CNR (National Research Council) /HCST-NCRD (Jordan, HCST/NCRD - The Higher Council for Science and Technology /National Center for Research and Developmentcon) joint research project "Raw earth constructions: study, recovery and innovation in materials and historical construction techniques" 2019. [37]

Furthermore, for the purposes of protection and conservation, the WHEAP program (World Heritage Earthen Architecture Programme) was launched by UNESCO with an inventory of raw earth heritage assets and recovery projects, identifying 150 earth sites that belong to the World Heritage Sites. and due to the seismic disaster that recently occurred in Morocco, it started a reconstruction program of the medieval Medina of Marrakech, largely destroyed by the earthquake.

Therefore, the use of resilient, eco-compatible biotechnologies, based on non-invasive multifunctional nanocomposites and biocomposites with durability requirements and privileged microbiological techniques, is fundamental, compared to the widespread use of biocides in which the integrability of the monuments is protected, with valorisation and also reuse, the health of operators, in a multi/interdisciplinary and cooperative relationship, furthermore geopolymeric materials are adopted for new raw earth constructions. According to the US international guidelines, 2019 *ACI 434-Acceptance Criteria for Masonry and Concrete Strengthening Using Fiber-Reinforced Cementitious Matrix (FRCM) Composite Systems - ICC Evaluation Service, and RILEM guideline TC 250-CSM &ACI 549 - Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) and Steel Reinforced Grout (SRG) Systems for Repair and Strengthening Masonry Structures* si adottano nanotecnologie a base di carbonio e PBO for the new fibre-reinforced composites with an inorganic matrix with the function of adhesive and which surpass the FRP (Fibre Reinforced Polymers) composites with an organic nature matrix based on epoxy resins in terms of resilience performance. [38]

In particular, the FRCM (Fiber Reinforced Cementitious Matrix) are composed of nets, made up of meshes with a maximum size of 30x30 mm, with long fiber with a high elastic modulus greater than 15%, tensile strength greater than 20% which represent the reinforcement made up of different materials and of which basalt, aramid, carbon, PBO (Polyparaphenylenebenzobisoxazole), basalt fibers and high-strength steel fibers which, in the form of strands, create corrugated surfaces for the best adhesion between the reinforcement and matrix, alkali-resistant glass, integrated into the inorganic cement or lime mortar matrix. The latter are added with percentages not exceeding 10% to guarantee the durability, permeability and fire prevention properties, and in different formulations, depending on the interventions, thus ensuring effective adhesion to the materials of the substrate to be reinforced and to the structural fibers of the networks. The thicknesses of these reinforcements vary from 5 to 15 mm for single nets, and do not exceed 30 mm for overlapping nets.

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a


b

Batllò house in Barcelona, Spain (a,b) :

Fig.23. a. Façade after the restoration [39]

Fig. 24. b. Detail of reinforcement of arches, walls and vaults with reinforcement systems including FRCM [40]

These FRCM materials, among the many restoration and building recovery interventions, were also used in the 2020 restoration of the Batllò house in Barcelona, Spain, an eight-storey building pre-existing in 1877 created by the architect Emilio Sala Cortés, but it was restored and rebuilt, in part, by the catalan architect Antonio Gaudì in the period of modernism, in 1904 with a sandstone façade, in sinuous projecting shapes representing balconies and inclined and forged chimney roofs, in a varied composition of colored mosaics (Fig .23, Fig.24). The restoration work by the architect Joan Olona and others mainly concerns the facade, the main floor with the recovery of almost all the plaster and the chimneys of the roof with the upper and lower part of the courtyard. For the walls, arches and vaults, reinforcement technologies were used for the recovery and conservative restoration in which the authenticity and integrity of the work stands out, in the adoption among the materials, FRCM fibre-reinforced composites, in glass fibre. A.R. alkali resistant, with premixed, two-component cement mortar, based on pozzolanic and fibre-reinforced binders. The house recognized as a UNESCO heritage site was partially intended by the owners for a museum, cultural events, etc. in which visitors also have the opportunity to have an interactive and immersive experience with smartphones and digital applications, for an augmented reality of the environments by Gaudi. From the modernist period there are multiple recent restoration and conservation interventions in the context of urban regeneration, such as the example of 20th century industrial architecture in Malaga known as "the ship" included in the Spanish DOCOMOMO register for the conservation of works urban. But in the context of urban regeneration with valorisation and redevelopment of buildings, in Rome, among other recent historical and modern restorations, there is that of the Mausoleum of Emperor Augustus, with a diameter of 90 m and a height of approximately 45 m, from the 28th century BC, with the arrangement of the external spaces, designed by the architect Francesco Cellini and others, and carried out by Roma Capitale with the aim above all of redeveloping the area to be used as a public space in a qualitative relationship of use of the asset represented by the monument. Therefore restoration and redevelopment interventions with innovation of materials and construction technologies with the use of FRCM which indicate the combination of a fibrous phase resistant to traction which integrates into a matrix with excellent adhesion properties to the support to be consolidated and is also called TRC (Textile Reinforced Concrete), TRM (Textile Reinforced Mortars), IMG (Inorganic Matrix-Grid composites). They are resilient materials with high mechanical performance for structural reinforcement capable of absorbing the efforts of overloads and anti-seismic insulation in concrete structures, masonry for modern and historic monumental buildings, for the conservation of cultural heritage according to the different types of intervention . In particular for the protection and safeguard against seismic action in new reinforced concrete structures and in pre-existing historic masonry ones, among the innovative anti-seismic dissipative systems the hydraulic devices stand out, appropriately chosen for each individual case, with prevented instability (Shock Transmeitter Unit or STU), and in shape memory alloys (Shape Memory Alloy Device or SMAD with seismic isolation strategies. For the survey in particular typologies for a functional reorganization of the building, the use of reinforced plasters is required, the recovery of floors, and the diagnosis, starting from analysis with a collection of data, a geometric survey is defined which is followed by the processing of another into a 3D structural geometric model and subsequently into a FEM (Finite Element Method) mathematical model, in which the structures are detected and intervened on with necessary simulations.

They are obtained with the aid of automatic meshers with non-linear analysis and in the presence of the dynamics of the building in which the various expulsions of structural components have not occurred. For the application of materials in the restoration and recovery project of FRCMs, the CNR, there are CEI-UNI-CNR national regulations. Furthermore, the 2019 Italian guidelines of the Superior Council of Public Works are in force: Guideline for the identification, qualification and acceptance control of inorganic matrix fibre-reinforced composites (FRCM) to be used for the structural consolidation of existing buildings, [38] with a valid contribution to the round robin drafting of the RILEM TC 250-CSM between European laboratories and universities.

The European standards and technical specifications to which the fibres, threads and mortars as matrices of FRCM composites must comply are UNI EN 13002-2 and ISO 13002 for carbon fibres, UNI EN 13003-1-2-3 for aramid and PBO fibres, ISO 16120-1/4; EN 10244-2 for steel wires etc.

Therefore at a procedural level in a restoration project both for structural consolidation and for seismic and gravitational loads through the use of FRCM (Fig.25), of good chemical-physical compatibility with masonry and concrete substrates, there are also these European and national regulations in force with indicative intervention strategies for the design, execution and control of historical artefacts on the technological system of the building. In particular on the classes of foundation, elevation and containment load-bearing structures through reinforcements to masonry structures (arches and vaults, confinement of masonry pillars, floor and top curbs, wall panels), instead reinforcements on concrete structures (nodes between /pillar, confinement of pillars, floors, flexural reinforcement of beams, pillars and floor joists, shear reinforcement of beams and pillars, anti-overturning of infills, reinforced concrete partitions, of bridges and more).

For example, for anti-seismic reinforcement on the intrados and also on the extrados of vaults or masonry arches to increase tensile strength and contract the opening of the hinges, plating with bands of nets or unidirectional fabric, in carbon fibre, is used galvanized with very high resistance, and with hydraulic lime-based mortar, while for floor kerbing an external kerbing is applied with fabric bands that surround the building or with reinforced masonry top curbs through the application of horizontal mortar joints of FRCM reinforcement networks. For concrete structures and small sections such as floor joists, PBO mesh with a high-performance inorganic matrix is applied, (Fig.25. a,b).

a b

Fig. 25 (a,b) . Application of FRCM on vaults: a. [41], b. PBO and carbon long fiber reinforcement FRCM on reduced section concrete structures (such as floor joists) with 105 g/m² unidirectional PBO mesh and MX-PBO Concrete inorganic matrix. [42]

Conclusions

Technological innovation reveals, in all construction sectors, the application of products and systems that satisfy the performance needs of the different results in the new design process, above all with a view to valorisation and resilience in which sustainable digitalisation strategies are highlighted . In particular, the restoration project with the recovery and redevelopment of the cultural heritage, and for the reduction of seismic vulnerability and prevention against various environmental, anthropogenic and natural disasters, through an efficient design process model with innovative technologies of intervention in efficient Master Plans and networks with scheduled maintenance and timely checks and which highlights a multi/interdisciplinary participation of skills, Bodies, Universities, in scheduled maintenance and continuous checks, aim precisely at achieving these objectives in compliance with laws and regulations national and international regulations, and in line with ICCROM, UNESCO, UNFCCC, Paris Agreement, ICOMOS, New Technology, COP27 Cleantech, IT and ITC etc. They are mainly based on transmitting to future generations the historical, architectural and landscape heritage in its authenticity and integrity by interacting with users for the purpose of potential enjoyment with possible adaptive reuse of the architectural artefact, in the different distribution forms and types of settlement, in compatible urban redevelopments and regenerations, which include the revitalization of external spaces with recontextualisation and valorisation of monuments.

The restorative design intervention criteria are based on a practice of reversibility, distinguishability, minimal intervention and chemical-physical compatibility, with innovative intervention methodologies which highlight non-invasive diagnostics and monitoring with digitalized ITC technologies, for a follow-up of the state of degradation, for the protection and conservation of monuments with use of detection technologies, from the application of HBIM to the use of 3D/BIM laser scanners, photogrammetry, FEM modeling and more. Use of scanning microscopy with SEM-EDS technology, and many other detection methodologies, diversified tests for the state of absorption by capillarity for condensation, etc. structural monitoring with intelligent wireless sensor technologies, sensors such as SMOOTH, MEMS for intelligent data return.

Therefore resilience and sustainability with nanotechnologies and structural and conservative reinforcements for efficient eco-compatible interventions, with low environmental impact, to counteract the phenomena of degradation, biodeterioration from various causes including environmental ones, natural seismic disruptions, hydrogeological disruptions, anthropic activities and more with application of durable and reversible natural materials, such as for raw earth constructions. For this type of construction, research, for the purposes of conservation and restoration and also for reconstruction, is mainly aimed at the engineering of natural materials, green building, reinforced with chemical stabilizers including metakaolin, lime, natural additives, geopolymeric materials, all innovation of construction systems and use of biotechnology. Furthermore, the application of intelligent and resilient materials and technologies for the restoration and consolidation of masonry, stone and reinforced concrete monuments is widespread with the use of composite anti-seismic materials FRCM with PBO and for seismic isolation with hydraulic devices, appropriately chosen to each individual case, with prevented instability (Shock Transmeitter Unit or STU), and in shape memory alloys (Shape Memory Alloy Device or SMAD). Finally, digitalisation, digital reality (DR) and virtual reality (VR) strategies with augmented reality as an interactive experience with immersive visualizations of the user and the places visited with 360° video technology and apps. The challenge is to pass on to future generations a sustainable architectural heritage as a document of historical, architectural, artistic, archaeological and cultural heritage value, through the adoption of a procedural operational model, in which to highlight the technological innovations in the restoration intervention with the use of innovative technologies that are resilient and sustainable from both an environmental, economic and social point of view.

Summary

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Credit authorship contribution statement

Mocerino Consiglia : Conceptualization, methodology, Writing – original draft, Investigation, Data curation, Validation
Abderrahim Lahmar: Visualization, Writing –review and editing
Mohamed Azrour: Visualization, Writing –review and editing,
Abdelilah Lahmar: Writing – review and editing, visualization, Validation

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] ICCROM, QUARTERLY REPORT 1, Rome, Italy 2023. https://www.iccrom.org/iccrom-strategic-directions-and-objectives

[2] UNESCO, Saving our World Heritage Brussels, Belgium 2022. https://en.dl-servi.com/product/saving-our-world-heritage

[3] ICOMOS-Post-Trauma_Reconstruction_Proceedings-VOL1-ENGok.pdf. 2016 https://openarchive.icomos.org/id/eprint/1707/1/ICOMOS-Post Trauma_ Reconstruction_Proceedings-VOL1-ENGok.pdf ;

[4] ICOMOS-Post-Trauma_Reconstruction_Proceedings-VOL_2_Final.pdf. 2016https://openarchive.icomos.org/id/eprint/1707/3/ICOMOS-Post-Trauma_Reconstruction_Proceedings-VOL_2_Final.pdf

[5] Marrakech - https://www.marocco.org/cosa-vedere-marocco/marrakech/cosa-vedere-marrakech/

[6]C.Brandi Teorie del Restauro, Einaudi Editore ,Torino, Ed. 2, 2000.

[7] V. Bokan Bosiljkov, A. Padovnik, T.Turk, Conservation and Restoration of Historic Mortars and Masonry Structures, Springer HMC 2022. https://link.springer.com/book/10.1007/978-3-031-31472-8?source

[8] Ministero della Cultura, Codice dei beni culturali e del paesaggio, ai sensi dell'articolo 10 della legge 6 luglio 2002, n. 137, Decreto Legislativo 22 gennaio 2004, n. 42 https://www.beniculturali.it/mibac/multimedia/MiBAC/documents/1226395624032_Codice2004.pdf

[9] UNESCO, Guidance and Toolkit for Impact Assessment in a World Heritage Context UNESCO, ICCROM, IUCN, 2023. https://whc.unesco.org/en/guidance-toolkit-impact-assessments/

[10] UNESCO, The Operational Guidelines for the Implementation of the World Heritage Convention, 2023 Operational Guidelines, WHC.23/01, 24 September 2023 https://whc.unesco.org/en/guidelines/

[11] Quando una scossa da 6.3 sfregiò L'Aquila e la provincia https://www.agi.it/cronaca/news/2021-04-06/terremoto-l-aquila-abruzzo-12065249/#

[12] La Francia e l'Italia fianco a fianco all'Aquila per festeggiare la rinascita della chiesa di Santa Maria del Suffragio, https://it.ambafrance.org/La-Francia-e-l-Italia-fianco-a-fianco-all-Aquila-per-festeggiare-la-rinascita

[13] ICR Normative http://www.icr.beniculturali.it/pagina.cfm?usz=5&uid=128&umn=71

[14] G.Carbonara, Restauro architettonico: principi e metodo, Ed. Mancosu Editore, 2013

[15] CNR, ISSMC, Soluzioni innovative per la conservazione del Patrimonio Culturale-Malte, 2023 https://www.issmc.cnr.it/ricerca/linee-di-ricerca/ambiente-edilizia-ed-patrimonio-culturale/beni-culturali/malte-idrauliche-a-calce-cl-e-nhl-per-il-restauro/

[16] V.Balboni, M.Montuori, M.Zuppiroli, Premio Internazionale di Restauro Architettonico "Domus restauro e conservazione-prima edizione ", in Paesaggio Urbano, Maggioli Editore 2-2011 https://www.paesaggiourbano.org/wp-content/uploads/2019/09/PU-2011_2-x-iPad.pdf Libro PU 2_11.indb

[17] Due anni fa l'incendio della cattedrale di Notre Dame, Vatican news, 15 aprile 2021 https://www.vaticannews.va/it/mondo/news/2021-04/due-anni-fa-l-incendio-della-cattedrale-di-notre-dame.html

[18] M.Héritier , A. Azéma , D. Syvilay , E. Delqué-Kolic , L. Beck , I. Guillot I, et al. (2023) Notre-Dame de Paris : The first iron lady ? Archaeometallurgical study and dating of the Parisian cathedral iron reinforcements. PLOS ONE 18(3): e0280945. https://doi.org/10.1371/journal.pone.0280945; https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0280945#pone-0280945-g001

[19] R. Roussel, L. De Luca, AN APPROACH TO BUILD A COMPLETE DIGITAL REPORT OF THE NOTRE DAME CATHEDRAL AFTER THE FIRE, USING THE AIOLI PLATFORM, ResearchGate GIUGNO 2023 https://www.researchgate.net/publication/371899955_AN_APPROACH_TO_BUILD_A_COMP

LETE_DIGITAL_REPORT_OF_THE_NOTRE_DAME_CATHEDRAL_AFTER_THE_FIRE_USING_THE_AIOLI_PLATFORM

[20] C.Mocerino, TOP OFFICE Tecnologie intelligenti di riqualificazione. 2017 Gangemi Editore International, november 2017, Roma- ISBN 978 884923540-L.

[21] Tomasz Jele´nski Practices of Built Heritage Post-Disaster Reconstruction for Resilient Cities. MPDI 2018, https://www.mdpi.com/2075-5309/8/4/53/htm

[22] Design by the author C.Mocerino. S.MARIA DELLA LUCE IN TRASTEVERE DI GRABRIELE VALVASSORI, in rivista PALLADIO, pagg.105/118, Ed.Istituto Poligrafico e Zecca dello Stato S.p.A. 2007, Roma

[23] Photos by the author C.Mocerino

[24] Veiga, Joao Pedro and others ; Environmental influences on historical monuments: a multi-analytical characterization of degradation materials, NASA/ADS, maggio 2020 https://ui.adsabs.harvard.edu/abs/2020EGUGA..2221804V/abstract

[25] S. Pescari a, Laurențiu Budău a, Clara – B. Vîlceanu
Riabilitazione e restauro della facciata principale di edificio storico in muratura – Opera Nazionale Rumena Timisoara, Elsevier, 2023

[26] Ministero della Cultura .La carta del restauro. 1972 Italia https://soprintendenzapisalivorno.beniculturali.it/wp-content/uploads/2019/08/circ-117-del-1972-Carta-del-restauro.pdf

[27] MotivexLab, Analisi SEM-EDS di contaminazione di superfici, Torino, Italia. https://motivexlab.com/analisi-sem-eds/

[28] CORDIS UE, Final Report Summary - SMOOHS (Smart Monitoring of Historic Structures), 2015 file:///C:/Users/lmoce/Downloads/CORDIS_project_212939_en%20(1).pdf

[29] G. Mastrobuoni, F. R. Nicosia, Piattaforma per il monitoraggio del Parco Archeologico del Colosseo, ASITA 2019, http://atti.asita.it/ASITA2019/Pdf/175.pdf

[30] Photos by the author C.Mocerino

[31] Natan Sinigaglia, Distorsion in space time, 2020, https://natansinigaglia.com/works/distortions-in-spacetime/

[32] Il team e il progetto Casa Batlló, https://www.casabatllo.es/it/si-di-noi/

[33] E.Ferraris, L’innovazione nel settore culturale museale, in Energia, ambiente e innovazione, rivista EAI Roma Italia, n.2/ 2023

[34]A. R.Sprocati, F.Tasso, C.Alisi, P. Marconi e G. Migliore, Biotecnologie in gioco verso processi e prodotti sostenibili per i beni culturali, ENEA in Energia, ambiente e innovazione, rivista EAI Roma Italia, n.4/ 2016, https://www.eai.enea.it/component/jdownloads/?task=download.send&id=376&catid=14&Itemid=101

[35] M. Bispo, Sostenibilità edilizia: case in terra cruda nel mondo , 5 luglio 2022 https://laterracruda.com/blogs/ecosostenibilita/sostenibilita-edilizia

[36] M. Trovato, Marocco: la Valle del Draa e le dune di Zagora, in Africa Rivista, 6 ottobre 2017, https://www.africarivista.it/marocco-la-valle-del-draa-e-le-dune-di-zagora/116659/

[37] CNR, PROGETTO COMUNE DI RICERCA Costruzioni in terra cruda: studio, recupero e innovazione nei materiali e nelle tecniche costruttive storiche, Italia, 2019,

https://www.cnr.it/it/accordi-bilaterali/progetto/2846/costruzioni-in-terra-cruda-studio-recupero-e-innovazione-nei-materiali-e-nelle-tecniche-costruttive-storiche

[38] ACI American Concrete Institut, RILEM TC 250-CSM &ACI 549 - Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) and Steel Reinforced Grout (SRG) Systems for Repair and Strenghtening Masonry Structures, November 2020, ISBN: 978-1-64195-120-3https://www.concrete.org/Portals/0/Files/PDF/Previews/549.6R-20_preview.pdf

[39] Casa Batlló: un restauro da record, REDAZIONE GREENME, 15 luglio 2019 https://www.greenme.it/viaggi/europa/casa-batllo-restauro/

[40] Mapei per Casa Batlló.Foto e video Gallery, 2022, https://www.mapei.com/it/it/realta-mapei/dettaglio/mapei-per-casa-battlo

[41] Sistemi di rinforzo delle strutture in calcestruzzo e muratura basati sugli FRCM, rivista INGENIO, Italia 11.11.2021. https://www.ingenio-web.it/articoli/rinforzo-strutturale-i-sistemi-frcm-ruregold-per-il-consolidamento-di-una-chiesa-a-troina/

[42] RUREGOLD, Sistema di rinforzo FRCM per calcestruzzo composto da rete unidirezionale in PBO da 105 g/m² e matrice inorganica MX-PBO Calcestruzzo, Solignano (PR), Italia https://ruregold.com/it/prodotto/pbo-mesh-105/