



3D model of Apulian polychrome majolica dome.

Polychrome majolica of Apulian domes: history, technique, pathology and conservation

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Abstract: The paper is focused on the historical-architectural evolution and material-technical qualification of polychrome majolica domes that were built between the 17th and 19th centuries in Apulian religious buildings. In particular, the cultural context in which this solution spread throughout the Mediterranean area is identified. Moreover, the case history of construction and decorative techniques that are distinctive of the regional territory is discussed in terms of underlying structure, installation of elements and surface colours. The study is then detailed on the Church of Santa Maria della Vetrana in Castellana Grotte (BA), for which the morpho-typological survey and mapping of the decay state are presented, based on the use of terrestrial and aerial digital photogrammetry. Finally, based on the identification of the main pathologies from both direct and indirect alteration factors, the most appropriate conservation and maintenance interventions are outlined, with specific focus on repair and integration of the majolica tiles, according to principles of high compatibility and low intrusiveness for a solution meeting artisan tradition and technical practice.

Keywords: majolica domes; aerial photogrammetry; 3D modelling; non-destructive techniques; restoration treatments.

1 Introduction

The application of the fundamental principles regarding the protection and enhancement of the Italian tangible and intangible assets, as stated by the Code of Cultural Heritage and Landscape since 2004, is ensured through crucial actions of identification, assessment, safeguard and conservation of such inheritance. In the contemporary scientific debate, “knowing in order to preserve” is a key concept, where the comprehensive acquisition of historical, technical and material information, supported by both documentary search and experimental investigation, is required to boost a correct critical approach to the intervention on the historical built environment (ICOMOS, 2003; Delgado, 2016; Orbasli, 2007). It is also noted that, in many cases, such knowledge is pursued with a scalar approach, leading to heterogeneous classes of thematic data and parameters, which are difficult to compare even on a historical level within a multidisciplinary process (Letellier, 2007; Ioannides, 2020).

Within this framework, the case of polychrome majolica domes, featuring the built landscape in many Italian and Mediterranean landmarks, is emblematic.

The scientific literature is focused on the topic, following two separate research lines that are found rarely convergent: on the one hand, the analysis and modelling of the “dome construction system” as structural and envelope component of religious monumental buildings (Zerlenga, 2021; Capone, 2022), on the other hand, the well-established research and characterization of the “ceramic material manufactured as majolica” (Coentro, 2012; de Viguerie, 2018). This work aims to triggering some theoretical insights and operational procedures toward an integrated approach for reliable assessment and compatible intervention on such heritage, based on understanding the original constructive and performance requirements of an architectural unicum of resilient materials and techniques and defining general principles and remedies for the degradation factors affecting these elements nowadays. Particularly, in order to address general principles and remedies for the degradation factors affecting these elements nowadays, the paramount role of digital methodologies, based on aerial photogrammetry survey and modelling, is herein outlined, since they enable low-intrusive, time-effective and extensive investigation of the whole structure-envelope-coating system, in typical conditions of low accessibility of surfaces and complex spatiality of interiors and exteriors (Baranwal, 2020; Federman, 2018; Percy, 2015; Quintilla, 2021; Miceli, 2020).

To this end, the paper is going to focus on the historical-architectural evolution and material-technical

qualification of polychrome majolica domes that were built between the 17th and 19th centuries in Apulian religious buildings, with specific attention to the cultural context in which this solution spread throughout the Mediterranean area and the case history of construction and decorative techniques (§2). Thus, a workflow is proposed for surveying and mapping the decay patterns of polychrome majolica domes, for the purpose of identifying the most recurring pathologies due to structural and environmental alteration factors (§3). The workflow, herein illustrated and discussed for a representative case study in Apulia Region (§4), is intended as a procedural scheme to be systematically replicated for a set of assets with homogenous historical, architectural and construction characteristics, in the view of structuring an inventory, for the benefit of technicians, companies and public administrations, and addressing appropriate approaches for repair and rehabilitation while respecting the inherent balance between artisan tradition and technical knowledge (§5).

2. Polychrome majolica domes between history and technique

2.1 Historical outline

One of the first Italian examples of polychrome majolica domes is certainly the Church of Santa Maria della Sanità in Naples, designed by the Dominican friar Giuseppe Donzelli (known as Frà Nuvolo) between 1602 and 1613 (Zerlenga, 2021; Pane, 1939). In addition to the characteristic structural system, the work of Nuvolo shows an innovative employment of the ceramic material, albeit commonly used already for mobile artefacts, thanks to the Spanish influence in the Campania Region. As a matter of fact, the Iberian Peninsula, beyond its influence on the Italian territory, represents a prolific hotbed of experimentations of the Middle-East contaminations and it becomes the West harbinger of the dialogue between the ceramic material and the domes, masterfully declined in the different local contexts. This applies also to South Italy, where the first experiences in Naples of the early 17th century triggered a variety of regional applications, particularly in Sicily and in Apulia from the late 17th century (Dell’Aquila, 1979).

Particularly, the research herein focuses on a peculiar geographical context such as the Apulia Region (Fig.1), where the construction and architectural practice, as well as the wise use of building materials, has resulted in living identity testimonies of a past time that must be transmitted to the future. Although there is no certain historical evidence, some scholars have speculated that the Apulian majolica domes represent memories

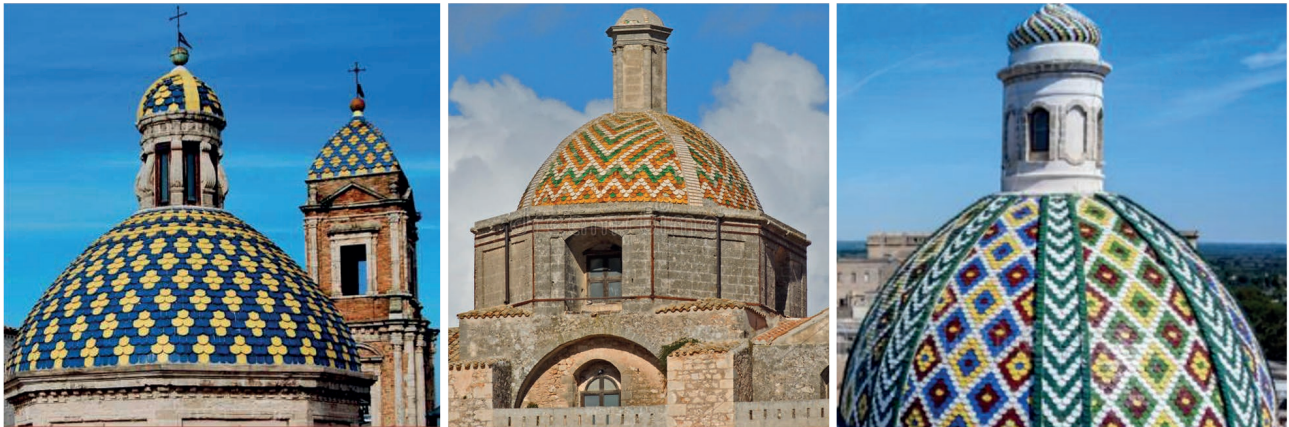


Figure 1 | Examples of Apulian majolica domes: (from top) Domes of Conversano, Oria and Ostuni.

of transformations occurred between the 17th and 19th centuries (de Cadilhac, 2018). Over the years, two territorial clusters are recognized, one in the North and the other in the South of the region. A possible explanation of these clusters is related to two seismic events. In particular, the earthquake of 30 July 1627 striking the Foggia area in the North and the event of 20 February 1743 occurred in the land of Otranto in the South (de Cadilhac, 2018). In both cases, the events profoundly marked the territory and the environment hosting these architectures and they triggered the need for reconstruction with novel solutions meeting both aesthetic and functional needs (Capone, 2022). The trinomial “needs, requirements and performances”, cornerstone of the technical architecture and building engineering, finds an excellent synthesis then, since the different use of a known material to cover the domes responded to an economic need (the majolica tiles were certainly less expensive and therefore most used in the past), stood out for its distinctive artistic-architectural connotation of splendour and power and rationally resolved the waterproofing of the extrados after post-seismic structural consolidation works (de Cadilhac, 2018; Picone, 2020).

2.1 Construction solutions

In general, the polychrome majolica domes, including the Apulian ones, might be classified according to the construction solutions, which are related to both the typological and structural system (e.g. simple, pavilion, braced or cloistered dome with rectangular, circular or polygonal base) and for the installation technique, arrangement and colours of the decorative elements.

Focusing on the latter classification, it is worth premising that a ceramic element is a clayey artefact, made

stable through a cooking process at high temperatures. The subsequent slow cooling phase allows to obtain a porous and opaque product, on which different types of coatings can be applied, including glass coatings, called crystalline if transparent and glaze if coloured, with the aim of giving the material waterproof properties and shine. Particularly, this procedure is applied to majolica, a term used for a particular ceramic production with metal stanniferous glaze coating. In fact, majolica, which owes its name to the island of Mallorca, an important Hispano-Arab production centre, are porous-paste ceramic materials protected by a finishing layer, engobe (opaque clay-based layer that can be permeable or waterproof) or glaze (impermeable glass coating) (Baratta, 2020).

There are also different methods of production, transformation and installation of these elements. In fact, beyond the most common rectangular glazed bricks, the dome mantle is often made out of shingles, namely roof tiles with an elongated shape along the vertical axis, ending in the lower part with a semi-circumference. In this solution, the ceramic might vary by size and geometry, having a width between about 17 and 20 cm, a length between about 25 and 30 cm and a thickness of about 2 cm to give greater mechanical resistance (Zerlenga, 2021; Dell’Aquila, 1979). In the traditional technique, the element has a small hole at about 4 cm from the upper part that houses the anchoring to the dome extrados through nails (Fig. 2).

Concerning the decorative design, it should be observed that the shingles are generally arranged according to rhomboid, herringbone or V-shaped patterns, by superimposing elements with different colours. The historical-technical documentation also reports on the different chromatic shades of the covering

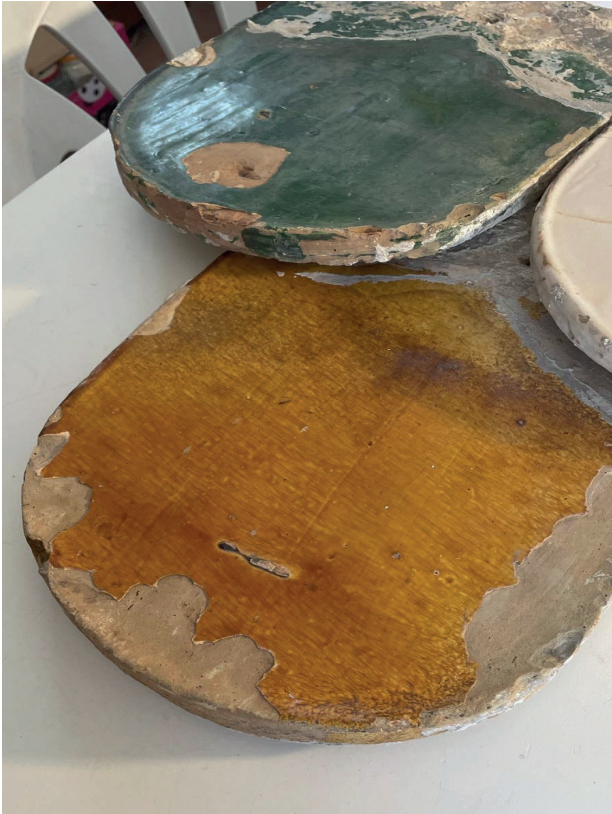


Figure 2 | Examples of Apulian majolica tiles. *Source:* Courtesy of Bottega Vestita srl, Grottaglie.

glazes, which go from white to yellow, from green to light blue, from blue to brown, red and ochre (Zerlenga, 2021; Dell'Aquila, 1979). Moreover, in many cases, the shingles, placed on the dome top towards the lantern, are resized and tapered for correcting the optical perspective, while keeping the formal motif (Dell'Aquila, 1979, Gattuso, 2013).

The installation of the shingles according to the “rule of thumb” takes place through the application of an underlying layer of *cocciopesto*, a mixture of brick and stone fragments, with lime sometimes enriched with oils and gypsum, and the fixing by copper nails to avoid corrosion, development of rust and potential damage of the elements. In most cases, the copper nails are still visible, while contemporary restoration have generally replaced them with zinc or brass elements (Dell'Aquila, 1979).

Taking into account the material and technical peculiarities of the polychrome majolica dome solutions, as well as their widespread presence in the architectural and constructional tradition of the Mediterranean area, methods and tools are highly desirable for documentation

/ assessment, on the one hand, and conservation / maintenance, on the other. These aspects are highly complementary and interconnected, particularly because the current practice in dealing with occurring obsolescence and pathology is oriented at replacing the original roof tiles with industrial, repetitive and standardized products, where the well-established principles of minimum intervention, compatibility and reversibility are subordinated to resource optimization and process control.

3. Methods and tools

The workflow for the decay mapping and condition assessment of polychrome majolica domes includes a series of tasks, following the preliminary research of historical sources and the direct observation of the state of the places. The activities follow the well-established process of anamnesis and diagnosis, including significant data and information on geometry, construction materials and decay patterns, toward therapy and controls (ICOMOS, 2003), by identifying suitable tools and procedures to guarantee technical feasibility, optimization of time and costs and reliability of the results. In detail:

T1. Digital Survey of the morpho-typological and material-constructive characteristics of the dome, the supporting structures and the envelope system of the internal space below. This survey can be conveniently performed with photogrammetric digital techniques, which allow the three-dimensional photorealistic reconstruction of an asset in a quick, cheap, simple and reliable way, starting from the acquisition of a sequence of photographic images. In consideration of the recurring operating conditions, this acquisition can be conducted “from the ground” with high-resolution cameras, possibly mounted on telescopic rods that can be elongated, for the intrados and internal surfaces, and by “aerial” photos and / or videos with drones outside. In any case, in order to obtain an adequate data set for the subsequent processing routines, the photographic images must provide for: an overlap between consecutive shots greater than 80% in both transverse and longitudinal directions with respect to the shooting plane; homogeneous lighting conditions, especially outdoors, where diffused light from overcast skies is convenient; and installation of control targets in significant points of the detected surfaces, for the purpose of scaling the processed 3D and 2D models.

T2. 3D Modelling for photorealistic representation, by processing the photographic images with SfM (Structure from Motion) and MVR (Multiview Stereo Reconstruction) procedures, in order to obtain coloured point clouds and textured polygonal meshes. These models, in addition to allowing the restitution of the plano-volumetric

complexity of the asset, allow the extraction of significant horizontal and vertical section planes, in the form of 2D CAD drawings and digital orthoimages, the latter particularly useful for the following thematic mapping.

T3. Decay Mapping, including the crack/deformation patterns, the humidity patterns and the surface alterations. The graphic restitution must comply with the reference standard UNI 11182: 2006 (Cultural heritage. Natural and artificial stone. Description of the alteration - Terminology and definition) and international guidelines by ICOMOS (Illustrated glossary on stone deterioration patterns). In particular, the former applies both to “rocks and mortars regardless of the function performed” as to ceramic materials (bricks, terracotta, etc.), referring explicitly, for some manifestations, also to vitreous coatings (e.g. cracks). Nonetheless, in the present study, two additional terms for the degradation of the majolica due to exposure to aggressive environmental and climatic agents were considered: (i) leaching, which occurs in conditions of acidic or neutral pH ($\text{pH} \leq 7$), when the water in contact with the surface extracts alkaline ions which are weakly bound in the glass lattice and, at the same time, enters the lattice forming a thin layer of silica gel on the leached surface (Charola, 1982), with opacity and iridescence effects of the coatings; (ii) corrosion, which occurs when the water is alkaline ($\text{pH} > 7$) and attacks the silicon-oxygen bond that forms the glass lattice, resulting in the disintegration of the coating (Campanella, 2007).

T4. Diagnosis of the state of conservation that must concern the structural and envelope system as a whole, also with a view to assessing the mutual interdependencies among the occurring phenomena. In particular:

- i. The crack/deformation patterns must be analysed taking into account the most common failure mechanisms of the domed structures, in particular for buckling, when the tensile stresses along the parallels, disposed towards the shutter, reach an intensity equal to the weak resistance to tension of the masonry and induce cracks along the meridians, so the structure expands in its lower band and is divided into many segments that behave, two by two, as independent arches.
- ii. The humidity patterns might be caused by phenomena of rainwater infiltration and/or vapour condensation, the latter more likely in summer due to the high thermal inertia of the structures, which have relatively cold internal surfaces on which the warm and wet air of the internal rooms can reach dew point.
- iii. The superficial alterations of the majolica tiles must be assessed in terms of direct and indirect deterioration

factors, where direct factors mean obsolescence processes linked to the characteristics of manufacture, installation and exposure of the elements, while indirect factors mean pathological mechanisms resulting from the bearing structure for static and hygienic-sanitary problems.

It is worth highlighting that, particularly in the diagnosis phase, the aforementioned need to integrate the specialisms is crucial, as related to the analysis, on the one hand, of the “dome construction system”, as the structural and envelope component of the building, and, on the other, of the “ceramic material manufactured as majolica”, with a view to identifying an harmonized strategy for reliable assessment and compatible intervention. In fact, for this kind of elements, the structural stability of the dome, the indoor comfort of the religious building and the durability of the coating are mutually affected.

For instance, the static failure of the structure results in cracks and deformations, which, in addition to the primary stability problems, induce stresses and strains that are transferred from the support to the roof covering, with secondary effects of detachment and/or fracture of the shingles and fixing materials/systems. In the same way, pathologies from infiltration humidity patterns can accelerate deterioration mechanisms of the porous matrix of the tiles, triggering or amplifying, processes of slow alteration from exposure to atmospheric agents (e.g. thermal oscillations, wind, pollution, direct rainwater,...) due to the presence of soluble salts in the underlying masonry structures. Nonetheless, the deterioration of the shingles necessarily entails the reduced watertightness of the roof covering, contributing to the initiation or propagation of infiltrations. Finally, the increase in weight of the materials soaked by meteoric waters can contribute, together with the morpho-typological configuration of the dome, to static instability of the structural system. Consequently, the comprehensive understanding of the occurring phenomena, in terms of main causes, concurring causes and interdependencies at the different scales, is necessary to point out integrated actions, which aim at structural reinforcement, dehumidification and recovery/conservation of material and formal surfaces, according to principles of minimum intrusiveness and maximum compatibility for a practice meeting artisan tradition and technical practice.

4. Case study

The Church of Santa Maria della Vetrana, located in Castellana Grotte (Ba), dates back to the 17th century and was built at the behest of Count Adriano Acquaviva

d'Aragona as a form of devotion and acknowledgement to the Virgin Mary for having put an end to the plague in 1681. The dome, with a circular base, is composed of four ribs that give it a slender profile and limit the fields within which the majolica shingles are arranged. The shingles are arranged in herringbone pattern in the colours of brown, white, green and light blue. The roof structure is set on an octagonal-shaped drum with regular splayed openings, one on each side of the octagon, and has a lantern with a circular base at the top. The drum is made of face masonry in regular and squared stone blocks. Inside, all the surfaces of the dome and the drum are plastered and enriched with decorative elements, e.g. pilasters, cornices, coats of arms.

4.1 Digital Survey (T1)

The dome was surveyed with digital photogrammetry techniques, based on acquisition of images, then processed with the above-mentioned SfM and MVR procedures, in order to obtain 3D models, as coloured point clouds and textured polygonal meshes. In detail, two complementary approaches were used: inside, a mapping of high resolution (18 MPixel) zenith images (153 photos), using a Canon Reflex EOS 100D digital camera and ensuring an overlap of about 90% among contiguous photos; outside, a video shooting in 4K using a DJI drone, whose flight was scheduled on a poorly ventilated and cloudy day around 12 am, to acquire clear images in homogeneous light conditions, with subsequent extraction of frames (n.250) with about 80% overlap. It should be underlined that the experimental set-up enabled a very reliable and efficient survey, especially if compared with the employment of Terrestrial Laser Scanning (TLS), which would have been: (i) more expansive, because it is nearly twice time-consuming in the acquisition phase and the equipment/operator rental service has double costs; more challenging, in terms of safety of the equipment/operator at the roof level; less complete, particularly for the reconstruction of the very top of the dome, whose coverage would require a drone anyway; less accurate for the documentation of colours and textures, since the photocameras embedded in TLS devices typically shows lower resolution than the ones that a drone could be equipped with.

4.2 3D Modelling (T2)

Both sets of images were processed by Agisoft Metashape® software, elaborating dense point clouds and textured polygonal meshes (Fig. 3), suitably scaled with the aid of control targets that were installed onsite before the acquisition.

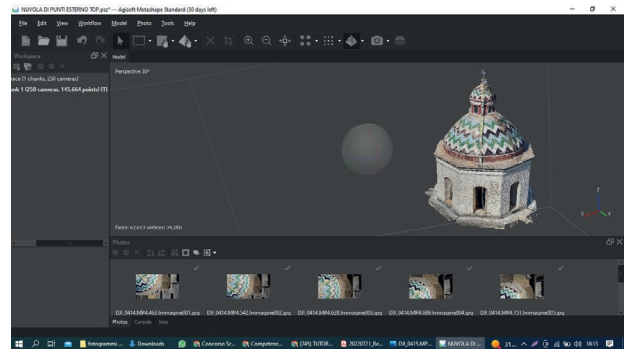


Figure 3 | Dense coloured point cloud.

4.3 Decay Mapping (T3)

The orthoimages, extracted from the photorealistic three-dimensional model, were used as a support for the accurate decay mapping of all the internal and external surfaces of the dome and of the underlying elements / spaces (Fig. 6).

In particular, from the overall analysis of the mapping results and in line with the workflow presented in §2, three macro-categories of alterations were found. Among them, the decay patterns that are most relevant for the purposes of the present study are: (i) Crack patterns of the dome intrados along the meridians of the cap; (ii) Humidity patterns on the dome intrados and on the internal wall surfaces, both localized and diffuse: localized, with efflorescence at the connection between the dome and the drum across the decorative elements, such as pilasters, cornices and coats of arms; diffuse, with chromatic alteration of the plaster, on the internal surfaces of the lantern (Fig. 7); (iii) Physical deterioration

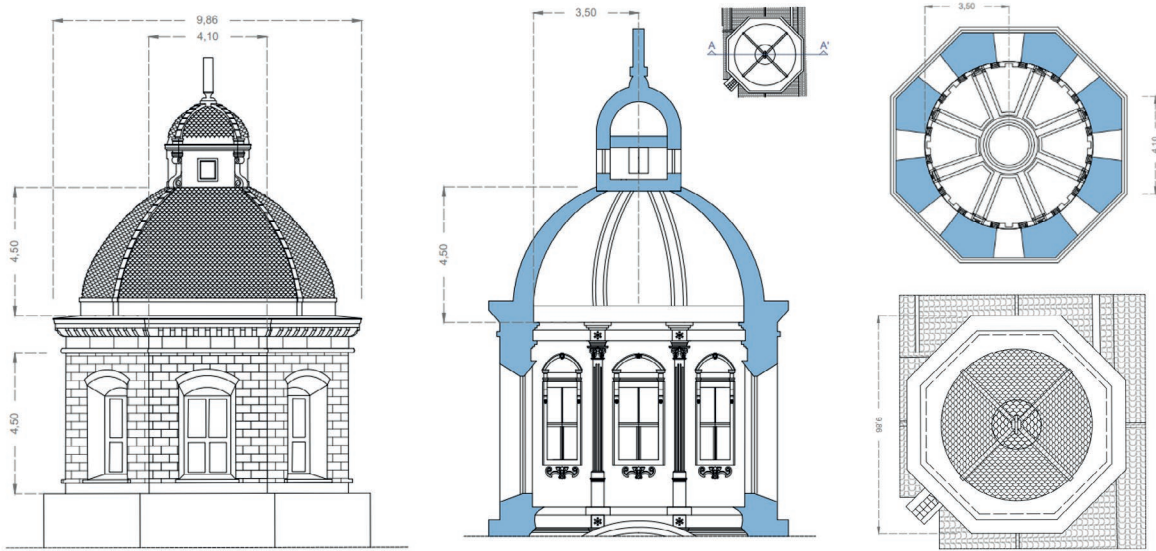


Figure 4 | Geometrical drawings.



Figure 5 | Orthoimages.



Figure 6 | Decay mapping, including internal cracks (green lines) and humidity patterns (light blue areas) and external missing elements (red), fracture of elements (purple), chromatic alteration (orange) and detachment of coating (light green).



Figure 7 | Humidity patterns of the intrados, including infiltration efflorescence at the dome/drum connection (top) and condensation on the internal surfaces of the lantern (bottom).

patterns of the majolica shingles, in the form of missing elements, fracture of the elements - with regular or irregular breaking line - detachment of the vitreous coating, chromatic alteration and leaching (Fig. 8).

4.4 Diagnosis (T4)

The joint analysis of the different forms of surface alteration enabled the integrated diagnosis on the state of conservation of the polychrome majolica dome.

In detail, it is noted that the shingles are affected by pathologies due to exposure to external atmospheric agents, which have compromised the physical integrity of the coating / element, eventually where manufacturing and installation defects occurred as well.

Furthermore, the spatial distribution and deterioration effects of the humidity patterns resulted in the identification of two different, albeit concomitant, phenomena: infiltration humidity from rainwater, which passes through the masonry structures, in particular in



Figure 8 | Decay patterns of majolica shingles, including fracture, detachment of the vitreous coating and chromatic alteration.

the connection points (e.g. dome-drum), is enriched with salts that crystallize on the internal surfaces during the evaporative processes and, thus, shows efflorescence stains; and condensation humidity, in particular in the lantern, where the top position of the element, the thermal inertia of the walls and the absence of ventilation through the openings, which are constantly closed, cause the transition to the liquid state of the indoor air vapour, especially in summer.

Finally, the crack pattern was related to the dome buckling, due to the evidence of lesions along the meridians that are typical for this kind of failure mechanism.

On the basis of the formulated diagnosis and the overall achieved results, the methodological guidelines for the recovery and restoration were then developed that, for the sake of brevity, refer below only to the repair / integration of the shingles.

It is worth mentioning that, in order to guarantee the replicability of the above-mentioned workflow phases - on the same case study over the time for monitoring purposes and on further case studies for wider investigation - regardless the tools and procedure that might undergo technological innovation, some key

parameters should be taken into account, including the decay mapping according to macro-categories (crack/deformation, humidity and surface alterations) and the diagnosis based on the identification of the mutual relationships among structural stability of the dome, indoor comfort of the building and durability of the coating.

5. Discussion of results

The deterioration of the majolica shingles, caused by both direct - interaction with the surrounding environment – and indirect alteration factors - buckling and infiltration humidity of the dome – requires different treatments to recover the physical integrity and performance reliability of the polychrome mantle, by ensuring the enhancement of its figurative value, on the one hand, and the efficiency of its waterproofing function, on the other. To this end, as first operational recommendation, the interventions should be carried out onsite, rather than offsite in specialized centres, in order to avoid laborious anastylosis procedures, as well as delicate works to remove the elements, with risk of fracture, especially where some support/shingle and shingle/glaze discontinuities are already detectable. Moreover, onsite interventions must rely on different methods and techniques, depending on the specific alteration, as well as on the most trustworthy laboratory treatments for repair, consolidation and cleaning of mobile ceramic artefacts, following artisanal procedures.

With specific reference to repair/integration of shingles with fractures and missing parts, the most appropriate approach depends on the regularity of the breaking line. If regular, it is feasible to integrate the shingles with new ones, similar in size and pigmentation, suitably serrated and chamfered with manual tools to match with the portion of majolica in place. If irregular, it is necessary to make a preliminary clay cast of the breaking line, for the offsite manufacturing of the complement to be integrated onsite. In both cases, it is, then, essential to proceed with the joining of the two fractions, to be carried out by fixing the new portion to the supporting structure with high-performance, deformable, fast-setting and hydrating cementitious adhesive and subsequent coupling of the two portions with sealant and single-component thixotropic polyurethane adhesive.

Otherwise, in case of detachment of the vitreous coating, it is advisable to proceed with micro-injections of silane-based solutions, suitably added with micronized silica, to avoid the effect of yellowing from exposure to ultraviolet radiation. Finally, in the presence of chromatic alteration and leaching, even on elements affected by the aforementioned alterations, it is emphasized that the

conservative interventions must be limited to cleaning treatments useful to recover the shine, but not the original colour. For this purpose, it is recommended the use of hand broom brushes, steel wool and synthetic sponges of varying hardness with the application of a mixture of soap powder, pumice powder and salt-free detergents.

6. Conclusions

The paper has intended to discuss some methodological guidelines and operational procedures for the conservation of ceramic tiles as roofing system for buildings of historical-architectural value, toward an integrated approach of reliable assessment and compatible intervention at the different scales of the construction component and of the material. To this end, a methodological workflow of onsite survey and decay mapping of polychrome majolica domes has been proposed, supporting the overall diagnosis of static instability, humidity pathologies and physical obsolescence, with particular attention to the mutual relationships between the ongoing defects and failures of the support-tile-coating system.

The attention to this remarkable architectural solution rises from the acknowledgment of its distinctive role as landmark of the built heritage and its landscape across the Mediterranean area. Nevertheless, it is elicited by the increasing tendency, within contemporary restoration works, to replace the original damaged elements with industrial ones, showing high durability, excellent mechanical resistance, reduced thickness and low cost. Such a practice, even if it guarantees an overall visual perception similar to the ancient one, might neglect those imperfections, colour shades and changing shine, that should be kept by methods and procedures of preventive and conservative maintenance against degradation phenomena.

Finally, it should be noted that nowadays ceramic-based products are very much oriented to the innovative design of industrial decorative objects. This brings out a double socio-economic risk: on the one hand, the clay material has gradually lost its creative potential in the construction of architectural elements, such as shingles, also due to high life cycle costs compared to serial products; and on the other hand, the new production centres have not kept the “artisan manufacturing tradition”, but they are attracting great interest towards cutting edge digital and additive manufacturing fields.

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