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Microscopic techniques and a multi-analytical approach to study the fire damage of the painted stuccoes from the Petruzzelli Theatre (Bari, Southern Italy)☆

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ABSTRACT

This paper reports a study of the effects of fire on the decorative stucco elements consisting of painted mouldings and decorations in the Petruzzelli Theatre in Bari (Southern Italy). The theatre was built at the end of the nineteenth century. In 1991 a fire caused serious damage to both materials and structure.
Visible damage to the decorations included various deterioration patterns. The fire-related effects on both plaster and painted surface layers were subjected to in-depth investigation under laboratory conditions by focusing on mineralogical, chemical and microstructural alterations. Methods used included Optical Microscopy, Environmental Scanning Electron Microscopy coupled with X-ray microanalysis, X-ray Diffraction, Fourier transform infrared spectroscopy and simultaneous Thermogravimetry–Differential Scanning Calorimetry.
De-hydration of the gypsum binder and oxidation of the iron compounds caused new mineralogical phases to form in the stucco plaster. In some cases, microscopic observation suggested that calcination of the lime binder may have occurred in thin layers under the surface. Significant microstructural modifications were detected in the form of cracks and microcracks, due to thermal shock and gypsum dehydration. Phase transformations affected the structural integrity and the colour properties of the stucco plaster to different extents, up to a maximum depth of around 2.5 cm, while fissuring due to thermal shock penetrated to greater depths.
Fire-related damage in the surface paint consisted of colour changes and/or disruption of the painted layers due to thermally-induced chemical reactions involving mineral pigments; detachment and burning of the painted layers from the direct action of flames, as well as accumulation of combustion deposits on the surface were also observed.

1. Introduction

This work investigates the fire-damaged plaster and painted layers of the decorative stuccoes of the Petruzzelli Theatre in Bari (Southern Italy).

The Petruzzelli Theatre (Fig. 1), inaugurated in 1903, is an important example of a nineteenth century "Politeama" (i.e. a venue intended for various forms of live entertainment). It was decorated with stucco elements, consisting of mouldings and decorations in greater or lesser relief, with painted layers on the surface. They were applied on the ceilings and wall surfaces, as well as on statues and around the boxes. In 1991 the theatre suffered an arson attack, which caused serious damage to the main auditorium, involving the collapse of the cupola and almost complete destruction of the furnishings and roof; the foyer was less badly affected, while the ticket office remained intact (Fig. 2).

Fire is one of the most serious factors affecting the integrity of materials and structures of the built heritage and can generate rapid and irreversible damage. In the case of fire, buildings need to be assessed for damage to ensure safety and enable appropriate repair to be planned.

Buildings suffer frequent fire events and there are records of considerable research into the effect of fire on a variety of materials. Concrete and concrete structures have been widely investigated, because of their extensive use in public and private buildings in modern societies [1–4]. Increasing attention has been devoted to the study of the effect of fire and high temperatures on the masonry structures typically used in the historic building heritage [5,6] as well as at the material level on a variety of natural stones used as main traditional building materials [7–11]. Fire is in fact a major risk for the Cultural heritage, with about one historic building being lost in the EU every day [12,13]. Over their long lifespan, it is likely that monuments and historic buildings will sooner or later experience fire that has a potential long-term impact on the performance of materials and structures. It is therefore an important factor of damage to be taken into account in the context of conserving

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Fig. 1. The Petruzzelli Theatre after the restoration.

buildings of historical and cultural value. The inheritance of past stresses due to fire has been found to condition the decay pathway of stone materials within historic structures [14].

In the high temperatures related to fire events, both natural building stones and concrete undergo a variety of physiochemical changes and mechanical damage affecting their characteristics and properties. Mineral phase transformation can occur, often leading to colour change [15–19]. Significant thermally induced microstructural modifications, due to intergranular and intragranular fissuring, can be caused by the different thermal expansion of adjacent mineral grains [8,20,21] or by the strongly anisotropic thermal properties of some minerals (e.g. calcite)

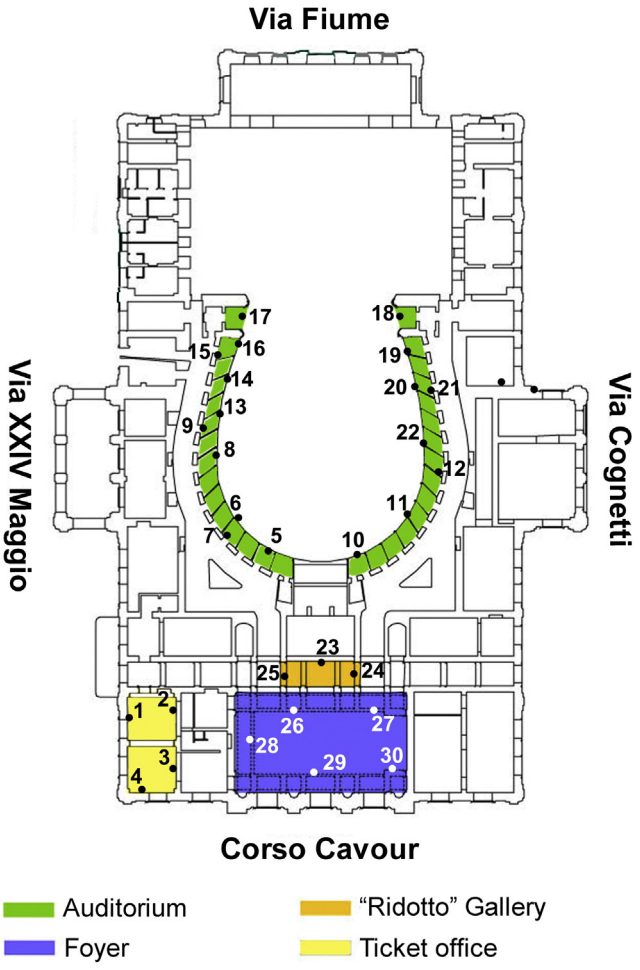

Fig. 2. Plan of the theatre and location of the samples (for easy reading, the figure shows only the number of the PT samples).

[22,23], especially in dense and compact stones; they can also arise from the volume change related to mineralogical transitions [15,16,24]. Microfissuring can lead to an increase in porosity [25,26] and to a reduction in mechanical strength [8,9,27]. Mechanical damage consists mainly of initiation and growth of cracks and microcracks due to thermal shock, and they can compromise the load-bearing capacity of stone and concrete [28,29].

Although they are the complementary materials of the stone units within historical masonry, mortars have been poorly investigated for fire damage [24,30]. One reason probably lies in the fact that their deterioration because of fire compromises the strength of load-bearing walls, so that they are generally replaced in order to maintain structural integrity. Plasters too, whether as a sacrificial layer for stone surface protection, or as a finish with an aesthetic function, are generally reapplied, given that their basic aesthetic properties have been lost. Investigations of historical mortar and plaster are mainly designed to determine their composition for the preparation of new repair materials which match the original and ensure compatibility.

Thermal effects on mineral pigments in laboratory conditions are known in the literature [31–33]. The effect of high temperatures on painted layers has been investigated in relation to the use of laser cleaning techniques [34,35]; there is little literature concerning the transformation of pigments within painted layers in the real conditions of a fire [36–38].

The study of the painted stuccoes of the Petruzzelli Theatre was a part of wide-ranging diagnostic investigations carried out on the structures and materials after the fire in order to plan the restoration works and repairs. It was motivated by the artistic and historic value of the decorations, so it offered the opportunity to investigate the effect of high temperatures and fire on both plaster and paint.

The investigation was divided into two phases. The first phase consisted of an on-site visual inspection. Then samples were taken for petrographic examination and analytical study in the laboratory. Optical Microscopy with transmitted and reflected light and Environmental Scanning Electron Microscopy and multi-analytical techniques including X-ray microanalysis coupled with ESEM, X-ray Diffraction, Fourier transform infrared spectroscopy and simultaneous Thermogravimetry–Differential Scanning Calorimetry were used to detect thermally induced effects on the microstructure and mineralogical–chemical composition of the stuccoes.

2. Visual survey on site

On-site investigation of the fire damage carried out by visual inspection revealed that the fire was unusual as the location of the source of the fire was very extensive, due to the presence of large combustible materials, such as wood and soft furnishings. The worst damage was observed in the auditorium (Fig. 2), where the fire is known to have started, and the decorations were directly affected by the flames or by the extremely high temperatures. The "ridotto" gallery was also seriously damaged. In contrast, in the areas furthest from the heart of the fire, such as the foyer, the damage appeared to be basically due to the effect of high temperature fumes. Very few parts of the theatre, such as the ticket office, were not affected by the fire.

Visually apparent damage induced by heating and flames (Fig. 3) was recorded. The observed deterioration patterns were classified according to the ICOMOS-ISCS glossary [39]. These included missing parts, scaling, spalling, cracking, and colour changes of the stucco decorations; powdering was also observed. Burning of the painted layers was visible in the areas directly affected by the flames. Widespread blackening of the surfaces was caused by smoke on the surfaces.

3. Materials and methods

The decorative stucco elements consisted of painted mouldings and decorations in greater or lesser relief present on the ceilings and walls,