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Research Article

Presentation of Efforts Aimed to Rediscover the Forgotten and Lost Aspects of Byzantine Fresco

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Abstract

Fresco painting (*al fresco*) is one of the oldest and most durable mural techniques. Although mosaic art is more resilient, it does not strictly fall within the category of painting. Christianity adopted the ancient technique of fresco painting for the depiction of religious themes on walls shortly after its emergence. After the Great Schism between Eastern and Western Christianity (1054 AD), Western art gradually began to diverge from the common fresco method practiced until then, adopting less demanding variations such as the *giornata* technique. In these methods, the wet plaster layer is thin, the paint layers superficial, and pigments are fixed with organic binders applied onto the thin plaster surface - a hallmark technique of the Renaissance. In contrast, the Eastern tradition largely maintained its adherence to ancient practices, employing thicker layers of fresh plaster, pronounced and thick paint layers (*impasto*), and the use of organic agents to retard drying and enhance the vividness of colors - characteristics of Byzantine or Orthodox fresco painting. The scarcity of extensive literature on Byzantine fresco painting, compared to the abundant bibliography on Renaissance frescoes, combined with the decline in its use in Eastern Europe, has created significant gaps in its contemporary application. Consequently, numerous artistic and technical elements that contributed to the perfection of the works have been lost. The aim of the present study is the comprehensive revival of Byzantine fresco painting, in order to preserve the high aesthetic and technical excellence that characterized its peak period (9th-15th centuries AD). Specifically, it investigates the use of plenty organic materials in plasters and pigments, given that recent physicochemical analyses as Raman spectroscopy, infrared spectroscopy, etc., have identified protein- based organic compounds not only on the surface but also in deeper layers of ancient monumental frescoes. Drawing upon forty years of field experience, we present effective practices intended to strengthen efforts for the preservation of Byzantine fresco painting and to prevent its irreversible loss, which would constitute a significant blow to art and culture.

Keywords

Orthodox, Byzantine, Fresco

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1. Introduction

Although the technique of fresco painting is thought to be relatively well-known from contemporary research, many details, particularly those related to Byzantine frescoes, remain unknown, overlooked, or confused.

Fresco painting demands not only artistic knowledge but also technical expertise, encompassing the full spectrum of processes from scaffold arrangements, masonry and cultivation of plant-based raw materials (such as flax) to the artistic application of paint. As such, a fresco team must consist of artists, painters, craftsmen, builders, cultivators. This was at least the case during its flourishing years. Also for a good fresco painter, it is highly beneficial to possess academic knowledge regarding the materials used.

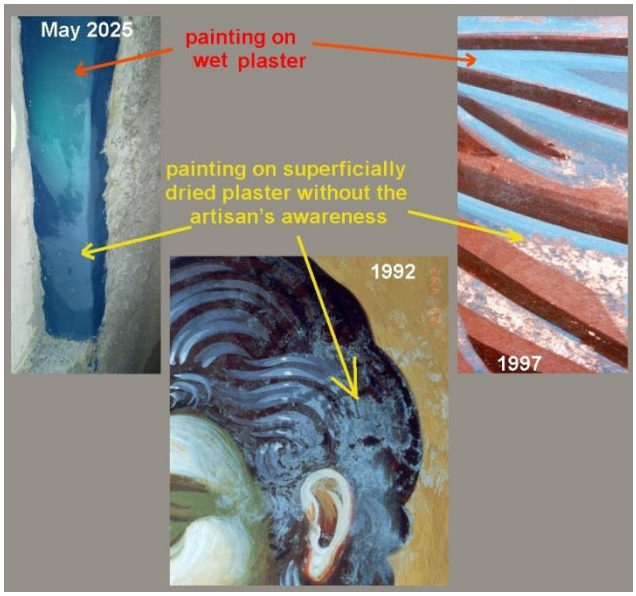

Figure 1. *Painting on plaster that was believed to be wet, but which had locally dried without being noticed. Within a short period, anything painted on the dried section will be discolored or deteriorate (from our work in Attica, Greece).*

Fresco painting (ἐφ' ὑγροῖς) constitutes a specialized technique of mural decoration executed on wet-freshly applied lime plaster wall surfaces. The unique durability and technical advantages of fresco method are contingent upon the artist's ability to complete the painting process while the plaster remains wet. Should the plaster dry before completion, the work transitions into secco painting-applied on dry plaster substrates-with considerably reduced longevity and resistance to degradation. Figure 1 illustrates what happens if a section of the fresh plaster dries before the painting work is completed. Initially (upper left at May 2025), the entire depicted blue area was painted uniformly, within the same time frame, and the painted surface appeared uniform, visually homogeneous, lacking any gradational effects, indicating consistent application of the pigment on the fresh plaster. We believed that the plaster was uniformly wet. However, after one day, areas of lighter and areas of more intense blue color appeared which were not initially distinguishable. The areas with intense blue color were those where the plaster underneath was indeed wet-calcium hydroxide during painting (thus constituting fresco painting)-while the lighter blue areas corresponded to plaster that had superficially transformed into calcium carbonate, meaning it had dried on the surface (thus turning into secco painting) without the artisan realizing it. Within a short period, the areas that appeared light blue may in the worst case, flake and peel off (as seen in the upper right photograph, 1997), or, in the best case, exhibit permanent visual deterioration (as seen in lower photograph, 1992).

Within the fresco technique, pigments are mixed with limewater to form a color mixture that is applied directly onto the damp plaster layer. To extend the workable period-that is, the time during which the plaster remains wet-and to preserve the vibrancy of the color tones, it is essential, in most cases, to add small amounts of organic additives into the limewater-pigment blend and/or into the plaster composition (this will be analyzed in greater detail below). Furthermore, the skillful manipulation of the trowel (the plaster application tool) plays a critical role in extending the time period during which the plaster remains wet, thereby enabling the execution of fresco painting.

The remarkable longevity and enduring brilliance of frescoes arise primarily from the mechanical integration of the pigments within the molecular matrix of the plaster (Figure 2). This bonding renders the pigments an integral part of the architectural substrate, providing both stability and resistance over time.

This publication is presenting, in a succinct manner, the empirical contributions of our Fresco Team to the study and application of this historic art form. It encapsulates the essence of our experience under the brilliant leadership of Sergios Sergiadis. Members of our team are the other two authors as well as additional contributors, whose names are acknowledged at the end of this publication. Our team is activated primarily in Europe (mainly in Greece, with occasional projects in Cyprus and Italy). The dissemination of the artistic, technical, and academic wealth of Byzantine fresco art and its application in the United States has been entrusted to the team member Kavallaris Emmanuil.

A plausible question from the reader might be: "Why is another study, specially a research article on fresco painting necessary?" The reason is that the fresco technique in the realm of Eastern Christianity gradually ceased to be widely practiced, with its use declining in the Balkans after the fall of Constantinople to the Ottomans in the 15th century AD. It is continuing to diminish until recent decades. It was progressively replaced by the secco technique (painting on a dry substrate-wall), which became the preferred method for wall painting, employing color-binding mediums such as oils,

animal or plant-based glues, and, more recently synthetic petrochemical materials (e.g. acrylics). It should be noted that the durability and stability of secco are significantly lower compared to those of fresco. In some cases, as in Romania, however, fresco painting remains a priority for the Romanian Orthodox Church.

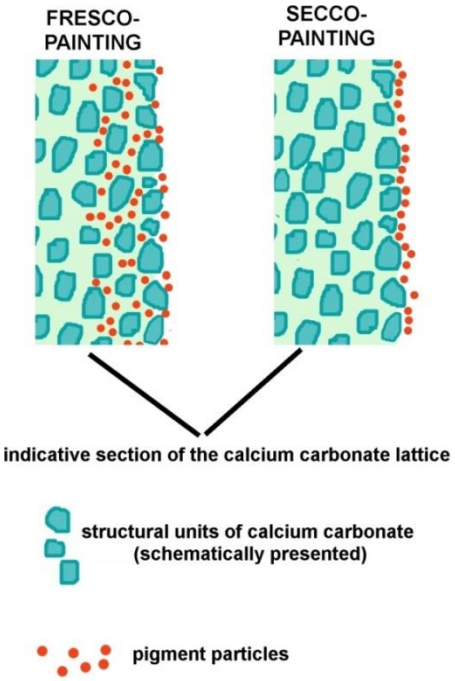

Figure 2. *Adhesion mechanism of pigment particles to the painted surface in the Fresco technique (left) and the Secco technique (right). The sizes of the structural units of calcium carbonate (green-blue) and pigment particles (red) are not proportionate to their actual dimensions.*

1.1. Academic Interpretation, in the Absence of Technical Craftsmanship Expertise, Can Result in Incorrect Conclusions

The application of physicochemical diagnostic techniques (Raman spectroscopy, IR spectroscopy, XRF-Xray fluorescence, among others) has significantly advanced the understanding of the chemical composition of mortars and pigments used in fresco works, shedding light on many aspects of this traditional technique. The systematic and reciprocal integration of physicochemical analysis results with the empirical knowledge and practices of fresco artisans is crucial for achieving a holistic understanding. Nevertheless, the technique of Byzantine fresco is rarely applied in contemporary practice; the number of active fresco workshops is significantly limited. As a result, a gap arises - an inability to confirm and cross-check data - between academic findings and the knowledge of the artisans, since the latter almost no longer exist. In most cases, the artisans of Byzantine fresco kept the techniques of perfecting their work as a professional secret, transmitting them only orally from generation to generation. They did not leave behind known technical treatises, such as those of Cennini, Vasari, Pino and others in the West. Even today, scientists cannot fully explain the exceptional durability of Byzantine frescoes in exterior settings, exposed to harsh winters, such as in the monuments of the 15th-16th centuries AD in Romania (Voroneț, Humor, Arbore, etc. - Figure 3).

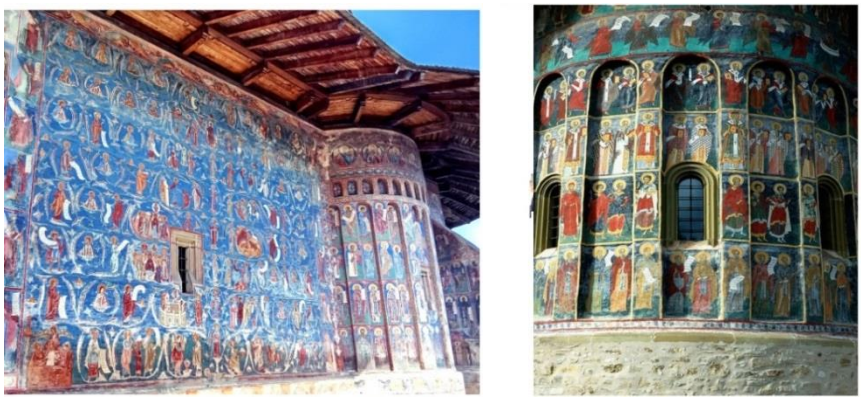

Figure 3. *Examples of frescoes paintings on the exterior walls of sacred temples of 16th-century, demonstrating remarkable durability under the harsh climatic conditions of northern Romania (Voroneț-upper, Sucevița-lower).*

It is known that the old masters used materials in the plasters and in their painting that are not known to us. Our team firmly believes that some of the materials that imparted such durability to the frescoes are organic materials (these will be addressed in the experimental section).

Below are some cases of incomplete or erroneous interpretation, due to the inability to compare, interact with, and correlate academic research data with the experience and knowledge of practitioners involved in the practical application of fresco painting, as such practitioners have now largely dis-

appeared.

For instance, in many old fresco works (dating back over four centuries), the background-the sky-appears black today. However, this was not the original intent. Early artisans applied black as a substrate and chromatic base for azurite, the primary pigment used for rendering the blue sky. Since azurite was expensive, it was applied sparingly. Over time, the blue pigment deteriorated, exposing the black substrate. This has led researchers and contemporary artists to the mistaken conclusion that the backgrounds of these frescoes were originally black.

Another example involves the vibrant orange-red hue of cinnabar (HgS). When used as a pigment on fresh plaster, cinnabar undergoes alteration. It remains stable only if mixed with an organic additive in lime water during the painting process, as demonstrated by our experiments (Figure 4). The chemical identification of cinnabar in monumental Byzantine frescoes, retaining its original hue even after several centuries, strongly indicates the deliberate addition of organic substances during the painting process.

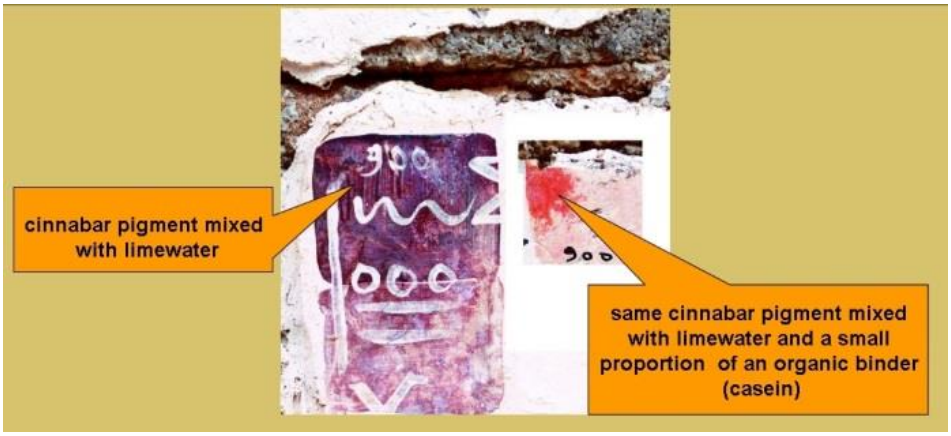

Figure 4. *Image from our experimental archives demonstrating that pigment cinnabar, when incorporated into fresco painting on wet plaster, undergoes chromatic alteration (left- here turned into purple) unless combined with an organic binder along with limewater (right), thus preserving its vibrant orange-red color.*

Azurite ($2CuCO_3.Cu(OH)_2$) is transformed, due to various factors (reaction with the alkaline environment of the plaster, oxidation, etc.), into green malachite ($CuCO_3.Cu(OH)_2$). Some contemporary academic researchers, attempting to identify the pigments used in ancient frescoes, would erroneously conclude that the painter employed a green pigment (malachite) instead of the actual blue (azurite).

Another characteristic example of misinterpretation regarding fresco techniques is the following. Researchers detected organic materials (e.g., egg) in 14th- and 15th-century frescoes in the Greek region. There is a widespread and deeply rooted view that fresco painting is executed solely by mixing pigments with lime water, a view that is incomplete and sometimes incorrect. The researchers, based on the above findings, misinterpreted the presence of organic material in their samples. Specifically, they concluded that, since the work contained organic material, it was painted on dry plaster (secco), e.g., egg tempera [1], p. 95. This occurred due to the absence of knowledge of the empirical technical elements possessed by a fresco painting team, which escape the attention of purely academic researchers [2, 3].

The truth is, that without organic material in the mixture of lime water and pigments, in most cases the work fails. Interdisciplinary, also in this case, is essential.

1.2. Description of a Cross-section of a Typical Monumental Fresco Painting

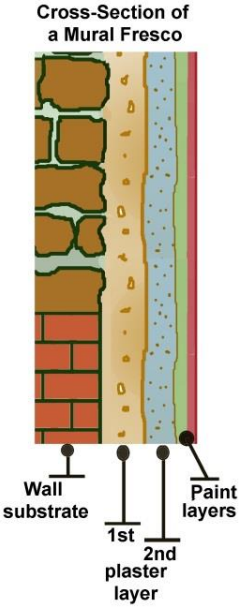

Figure 5. *Cross section of a mural fresco- the layers' thicknesses may not correspond to their actual proportions.*

Frescoes are typically composed of three major components: the masonry-wall substrate, the plaster (with its successive layers), and the painted surface (with many layers) (Figure 5).

A) *The wall substrate* serves as the support, the stable structural surface upon which the frescoes are executed. The structural surface-wall or ceiling-must be as stable as possible, free of friable coatings. The wall may consist of stone, brick, marble, or other materials.

B) *The plaster (with its successive layers).* It generally consists of two layers (details for each layer will be provided below), although references in the literature also report a greater number of layers; for example, Vitruvius [4] mentions a number of plaster layers ranging from 2 to 6. Usually the 1st layer is called arriccio and the 2nd is called intonaco.

C) *The painted surface.* The paint layers are applied using limewater and pigments, which are previously tested to ensure resistance to the alkaline substrate of the wet calcium hydroxide. In most cases, the use of one or more organic materials in small quantities is imperative. Examples of such organic materials include fish glue, egg yolk, starch glue, and many others (a more detailed discussion about the used organic materials will follow later).

1.3. Essential Differences Between Renaissance and Byzantine Fresco

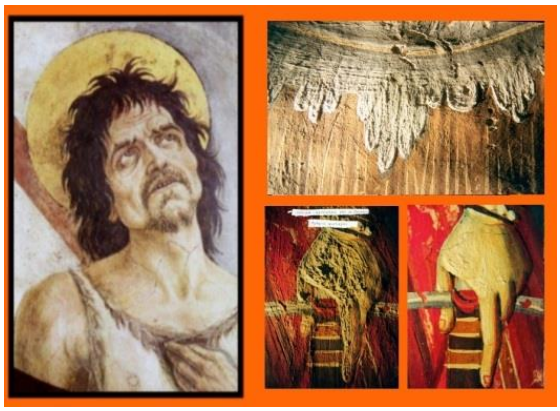

Figure 6. *The "aquarel-like" and light-textured representative example of Western fresco painting, is shown on the left (Saint John the Baptist, Domenico Veneziano, Basilica of the Holy Cross in Florence, mid-15th century AD), contrasted with the thick, flat, impasto-like colors of Eastern fresco painting on the right (Astrapades, circa 13th century AD). The thick paint layers characteristic of Eastern fresco require thick mortar layers and cannot adhere properly to the thin, superficial mortars used in Western fresco painting. (Photographs on the right are from our on-site documentation- details from Saint George painting of the artists Astrapades in the Temple of the Virgin Peribleptos Ohrid- Norht Macedonia).*

Until the Great Schism, the Fresco technique was practiced in a largely similar manner across both Eastern and Western Europe, following the traditions of antiquity. After the Schism, however, Western (Renaissance) fresco painting diverged significantly from its Eastern (Byzantine) counterpart. Western artists adopted less labor-intensive variations of the technique, whereas Byzantine painters continued to execute frescoes in the traditional way.

Some of the main differences between the two manners can be enumerated as follows:

The Western artists painted frescoes on a very thin plaster layer, using a much lower ratio of lime to aggregates compared to the Byzantines (1 part lime: 1 part aggregates, up to 1: 3, by volume). The thin layer of wet plaster dried very quickly and could not support thick layers of paint. The usual execution time for each section of the work was deliberately limited to one day (giornata). The chromatic layers also necessarily had to be thin. Also to fix the pigments on the very thin plaster, they used a high proportion of organic materials mixed with the pigments for painting. The Byzantines, on the other hand, used thick layers of plaster (especially the 1st layer-arriccio), which could reach up to 75% lime in the mortar composition (i.e., 3 parts lime: 1 part aggregates), and up to 90% (9 parts lime: 1 part aggregates) in the 2nd surface layer (intonaco) - proportions given by volume. The thick plaster layers, with appropriate adjustments, could remain wet for several days (one week is a common and standard timeframe for the completion of a section of a fresco painting), providing more time for painting. Moreover, they could support thicker, denser, and more opaque layers of pigments. Western frescoes were more ethereal and relatively translucent compared to the dense colors of the East (Figure 6).

Figure 7. *Fissure in the fresco-painted surface of the narthex at the Koutloumousi Monastery on Mount Athos-Greece, caused by structural deformation of the wall (earthquake, slight wall displacement). Straws of various materials can be seen, used as reinforcement and to prevent cracking (approximately 16-18th century A.D.), a practice extensively employed by earlier artisans. In our own fresco work, we also make wide use of similar materials (as described below). Horizontal distorting magnification has been applied to highlight the reinforcement materials. Photograph from our archive.*

Furthermore, Western artists removed the reinforcement (straws and fibers) from the plaster. Eastern artists used reinforcement materials in thick 1st layer arriccio to avoid cracks which inevitably were produced (Figure 7).

Figure 8. *Characteristic trowel marks on monumental fresco works of Byzantine fresco painting. Upper from Decani monastery in Kosovo (14th-century AD), two lower from Saint Dionysios Monastery, Mount Athos (17th-century AD)- from our archive.*

Another characteristic difference between Renaissance and Byzantine fresco was the use of the trowel. Eastern craftsmen made more extensive use of the trowel. They did not simply use it to spread the wet plaster on the wall, as Western artists did, but also employed it to break the superficial layer of calcium carbonate that had fleetingly formed where they were painting. If they did not break it, the pigment would not properly adhere to the surface, and even if it seemed to adhere initially, it would eventually flake off. The traces of this use of the trowel are visible upon careful observation in Byzantine frescoes, and even in fresco works from antiquity. Similar trowel marks are not observed in Renaissance frescoes (Figure 8).

We personally observed trowel marks (tool traces) during our field research on monumental wall paintings. Indicatively, we mention the following sites, although we visited many more.:

(a) at the National Archaeological Museum of Athens, on findings from Thera (Santorini, 17th century BC), in the Hall of the Monkeys, in the depiction of the Fleet, and in the curls of the young boxers;

(b) at the National Archaeological Museum of Naples;

(c) at Archaeological site of Vergina (Ancient Aigai) and in several intermediate works, with the most recent examples being the Church of Saint Paraskevi at Markopoulo, Attica, and the Monastery of Panagia Phaneromeni on Salamina, Attica (18th century AD) and many other analogous sites (Figure 8).

1.4. The Use of Organic Materials in Byzantine and Renaissance Fresco

The Byzantine craftsmen used organic materials mainly as retarders of the plaster's drying, to improve the workability of the mortar, and to ensure the exceptional durability of the final works under adverse conditions. The Westerners used them as binding agents to ensure the adhesion of the painting to the thin plaster.

2. Historical Elements of Fresco Painting

Fresco painting represents a form of mural art. Wall paintings, not executed with the fresco technique but as cave art, have been discovered and dated to approximately 51,000 years ago in Maros-Pangkep, South Sulawesi-Indonesia [5], among others as in the Lascaux caves in southwestern France, in the Altamira caves in Cantabria-Spain etc. Specifically, the fresco technique boasts an uninterrupted history from the Bronze Age to the present, although its implementation has alarmingly decreased in recent years.

Fresco painting first emerged in prehistoric times, with its origins appearing to trace back to Minoan wall paintings, in Crete-Greece [6-8].

Prime examples include the Theran frescoes from the prehistoric city of Akrotiri, in Thera- Greece [9] p. 17. The

technique is also evident during the Classical period in Greece and throughout the Hellenistic and Roman eras, as seen in the frescoes of Pompeii (e.g., the Villa of the Mysteries, 1st century AD) in Italy [10] p. 301 and the Tombs of Vergina (observed in situ by Sergios Sergiadis) in Macedonia- Greece. Moreover, Etruscan wall paintings were created using the fresco technique, [10] p. 26, [11] p. 321.

In the late Roman period and early Christian era, symbols and biblical scenes are found adorning Greek homes in southern Italy and the catacombs of Rome-Italy [11, 12]. Simultaneously, regions of Asia Minor-Turkey, such as Ephesus, Cappadocia, and Antioch, were adorned with fresco paintings [12, 13].

The fresco technique persisted through the Late Byzantine and Post-Byzantine periods, producing remarkable works of art. Notable examples include the frescoes of the Chora Monastery in Constantinople-Turkey, various frescoes in Serbia, the frescoes of the Peribleptos Monastery in Mystras in Peloponnese-Greece [14], and the Protaton Church in Athos Mount area-Greece, painted by Manuel Panselinos during the 13th-14th centuries [15-17].

Additionally, significant works were created in the Monastery of Stavronikita and the Monastery of Great Lavra in Athos Mount area-Greece [18] p. 82-89, as well as in the Monastery of Saint Nicholas Anapausas in Meteora-Greece [19] p. 358-365, painted by the Cretan artist Theophanes in the late 16th century.

In the 18th century, frescoes were created in the Church of Saint Paraskevi in Markopoulo Mesogaia in Attica-Greece by Georgios Markou and his students Georgios Kypriotis and Antonios Markou (1741-1751) and in the Katholikon (the central temple) of the Monastery of Faneromeni in Salamina-Greece (1735), also by Georgios Markou [20].

Significant fresco works are found in Serbia, Bulgaria, Romania, Moldova [21], Russia, Georgia, Armenia, and other regions (Figure 3).

By the 19th century, the fresco technique was abandoned, as Western techniques influenced by Bavarian rule entered Greece. From the 20th century to the present, examples of this technique have become rare, with notable exceptions including the frescoes by the painter Fotis Kontoglou [22].

In recent years, an increasing number of scientific publications-review articles, research and case studies articles- have been devoted to the investigation and study of materials, binders, pigments used in fresco painting in Europe as well as in other regions (e.g. North Africa, Middle East, etc.) [23-25].

Our research on the internet for efforts similar to ours yielded a number of publications, e.g., [26-28]. The attempt to revive fresco painting and its advantages is evident worldwide. It should be noted that in Romania, fresco painting, executed in a manner very close to the Byzantine tradition, has almost never ceased. Today, the painting of Orthodox temples is both the priority and the directive that painters are required to follow by the Official Romanian Orthodox Church. At this point, however, the following issues should be highlighted and clarified. Specifically, the term “fresco” is indiscriminately used for any mural painting (e.g., wall painting with acrylic materials or with potassium silicate paints), whereas the term fresco strictly refers to painting on wet lime plaster. It should not be forgotten that the term “fresco” means fresh, juicy, or cool. Also many papers use the term "fresco" indiscriminately, without specifying the differences between Byzantine fresco (e.g., by Panselinos) and Renaissance fresco (e.g., by Michel Angelo). Additionally, in contemporary publications referring to the revival of fresco, this revival includes the use of modern and synthetic materials, which largely derive from petrochemical products (derivatives of petroleum refining), the long-term behavior of which has not been tested, as petrochemistry has been widely applied only in recent decades. Moreover, there are already many studies and monographs highlighting the pathological effects of petrochemical materials in painting (at least in the form they have today) [29, 30]. As characteristic examples of the above trend, we note that a colleague working in fresco painting uses lime mortars for frescoes that contain acrylic additives (and not natural organic admixtures), while another colleague, for strengthening the mortar, uses, in addition to traditional flax fibers, polypropylene fibers.

The data recorded to date, together with the accumulated experience in the use of modern materials, raises serious concerns. It appears that the materials traditionally used by master craftsmen are demonstrably more sustainable, durable, and undeniably environmentally friendly.

3. Materials and Methods

In this section, we mention certain guideline proportions of the mortar components (lime, sand, straw, flax, hemp, organic additives) and of the paint components (limewater, pigments, organic additives). Deliberately and with full awareness, no further details are provided. Firstly, the scope of the present publication must be kept within specific limits; secondly, the condition of the wall, humidity, temperature, mortar consistency, available time, the “setting” of the materials, and many other parameters require continuous adjustment of the proportions.

It should be emphasized that in the present publication, we describe the materials and methods with which we have been working in recent years. These are the ones that have yielded the best results in our long-term experiments and have been incorporated into our practice. Occasional tests are mentioned, but what we present emphatically here represents the very best of our findings, which are also analogous to techniques from antiquity and Byzantine era.

We state in advance that one of the deepest «secrets» of the masters of fresco painting in the Byzantine technique is that *the organic binder, which is incorporated into the fresh plaster and mixed with the pigments applied to it, is largely responsible for the lustrous, brilliant, and exceptionally durable painted surfaces. Moreover, it delays the hardening of*

the plaster, thereby extending the available time for painting on the wet render.

The type of organic material may have varied from one chronological period to another, from place to place, and from one group of fresco painters to another. Below, we will present the range of organic materials that we have tested and employed over the course of our team's work.

The fundamental materials for executing Byzantine fresco painting are: *lime (well-slaked), river sand, mortar reinforcement materials (rye straw, fine flax fibers, or fine industrial hemp fibers), fine marble powder* (maybe small amount of fine quartz sand) and a variety of *organic compounds* (in small proportions).

For the preparation of the first plaster layer, all materials are used except marble powder and quartz sand.

For the preparation of the second plaster layer, slaked lime is used, and possibly a small amount of quartz sand (not organic compounds).

3.1. Slaked Lime-$Ca(OH)_2$ Production (by the Manufactures)

The specialized slaked lime producers follow the procedure described below: they receive limestone rocks, which are abundant in nature. Limestone means that the substance present in the highest proportion within them is calcium carbonate ($CaCO_3$). It is preferable for fresco works to use pieces of marble (which is high purity $CaCO_3$).

When limestone is fired at 900-1100 ℃ (ideally), it releases carbon dioxide (CO_2) as a gas and becomes solid quicklime (calcium oxide-CaO).

$$CaCO_3 \text{ (limestone)} \rightarrow CaO \text{ (quicklime)} + CO_2 \text{ (gas)}.$$

The solid product (quicklime-CaO) upon hydration turns into slaked lime (calcium hydroxide - $Ca(OH)_2$). This process is known as the *slaking of lime*.

$$CaO + H_2O \rightarrow Ca(OH)_2$$

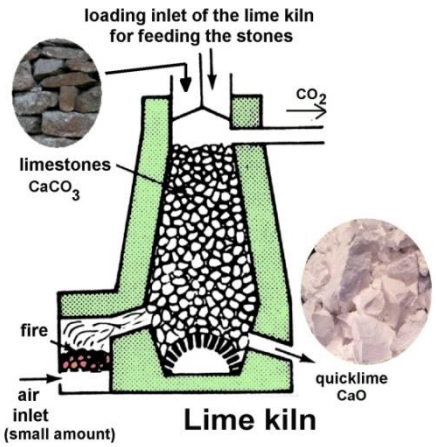

Figure 9. *Quick lime (CaO) production by heating limestone ($CaCO_3$).*

3.2. Lime Slaking Process Details

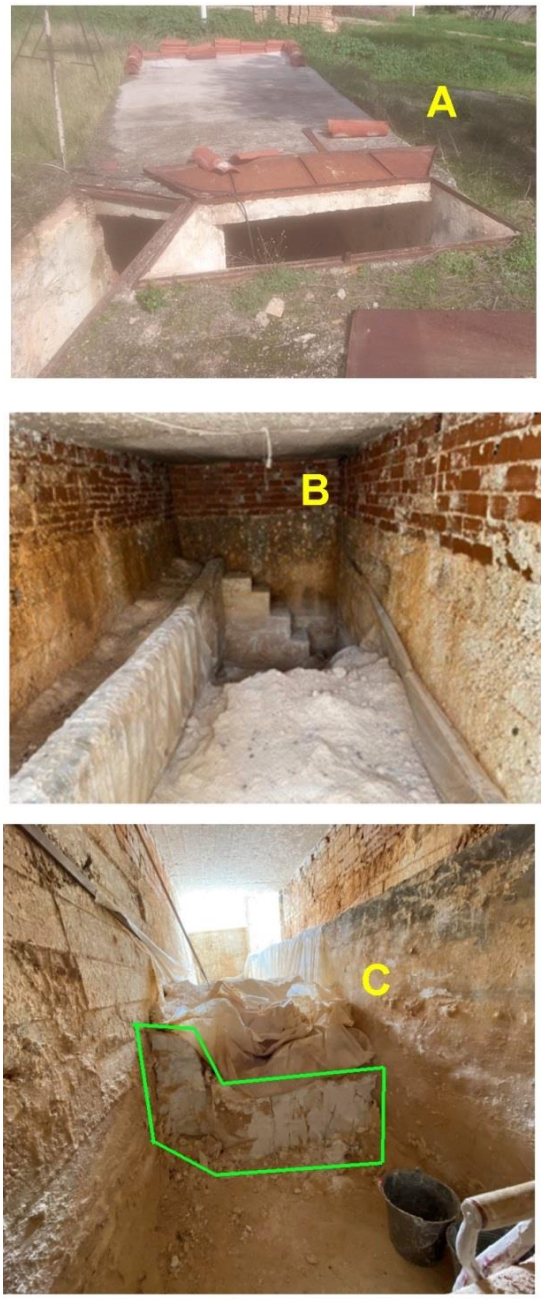

Figure 10. *The lime storage pit we use. It has been in operation since 1987. It is underground. Initially contained partially-quickly slaked lime (as purchased from the manufacturers), which turned slowly into more and more slaked lime- calcium hydroxide ($Ca(OH)_2$). This happened with occasional water replenishment, also above covered with a piece of nylon and a layer of sand both to prevent contact with atmospheric air. A: The lime storage pit viewed from above (from ground level). B & C: The underground interior of the lime storage pit. C: Within the green outline, a cross-section of the aged slaked lime ($Ca(OH)_2$) is visible.*

The lime producers immerse the quicklime (CaO) from the lime kiln into water for only a few days and then release it to

the market, for purely commercial reasons. However, the process of slaking has indeed begun but has not been completed. To reach completion, or at least an acceptable level, it requires a minimum of 6 months and can take several years. Thus, commercial and partially slaked lime is not suitable for fresco painting. Therefore, it is necessary to place the partially slaked lime purchased from producers into our own lime pit for many years under specific storageconditions. Our team lime storage pit which has contained lime slaking since 1987 is shown in Figure 10.

Why does quicklime require such an extended period to fully slake? The reason why is that the slaking process of quicklime (CaO) is exceptionally prolonged and cannot be characterized as an instantaneous on-off reaction. Within lime slurry there are always regions where complete hydration has not yet been achieved. Prolonged immersion in water ensures that these unhydrated CaO zones gradually diminish in size, progressively shrinking and transforming into fully slaked lime ($Ca(OH)_2$). As lime remains submerged in water, its alkalinity decreases, and its pH drops from 13-14 to lower values. An optimal pH value for lime intended for fresco painting is approximately 11.

Another method of lime slaking, which is more costly and additionally requires considerable expertise, is slaking with the use of wine. We shall not elaborate further.

3.3. River Sand and Assessment of Sand Suitability, Sieved Marble Powder, Fine Quartz Sand

The aggregate material in our mortar intended for the first layer of lime plaster (arriccio) is sand, preferably river sand. In our work, we use river sand because its grains are rounded and, when combined with the lime, they structure themselves and arrange in space more effectively. For better spatial arrangement, we require a variety of grain sizes. We aim the sand we are going to use, to be free of hygroscopic deposits adhering to its grains (e.g., clay), as these would absorb moisture from the atmosphere and create hydraulic stresses in the mortar. They would also hinder the adhesion of the lime to the grain surface. The presence of organic compounds, which are greasy, is likewise undesirable, as they similarly prevent the lime from adhering to the grain surface. Therefore, before using the sand, we subject it to cleaning by the following methods.

First, we remove water-soluble impurities. Specifically, we place the sand in a large container, cover it with water, stir the water with an agitator, and wait about 10 minutes for it to settle. If the sand had water-soluble deposits or impurities, the water that settles after stirring will be muddy. We discard the water and repeat the process until the surface water remains as clear as possible. Next, we spread the sand in a sunny place so it dries completely (Figure 11).

Second, subsequently, we aim to remove any residual greasy organic substances. A small portion of the dry sand from the previous process is placed in a container, and we add a solution of water and caustic soda (NaOH) or potash (KOH), which are bases that will saponify any fatty substances. The solution we use is approximately 3%, that is, 30 ml per liter. We stir well and leave it for about 24 hours. If the solution remains relatively clear, this indicates that the sand is suitable for use. If the two aforementioned procedures do not effectively clean the sand, then the sand is not suitable for fresco painting, and a new batch of sand is procured.

For the second plaster layer which is called intonaco, we use as aggregates sieved marble powder and sometimes very small amount of fine quartz sand.

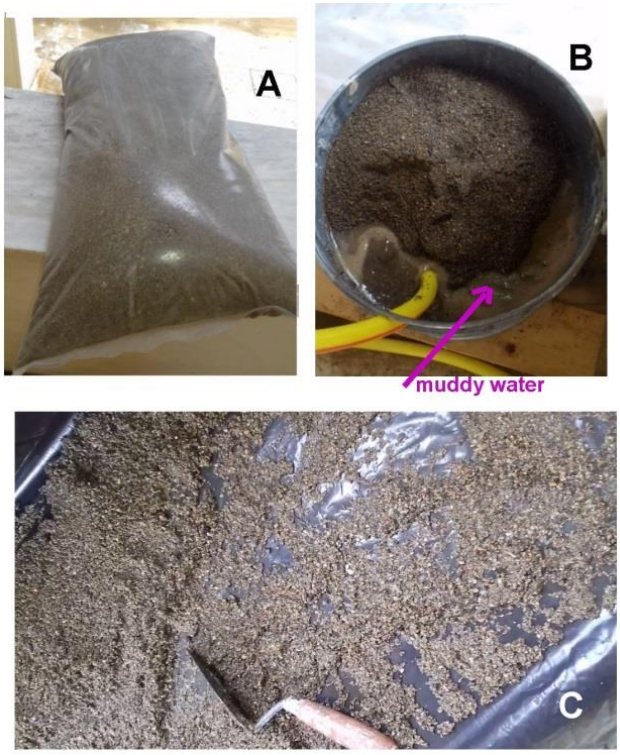

Figure 11. *Treatments with river sand. B: water wash, C: spreading of the wet sand to dry.*

3.4. Hardening Lime Plaster Procedure

When the mortar of slaked lime and river sand applied to the wall begins to harden. What hardening means?

The mortar of the fresco mainly consists of slaked lime and aggregates materials (sand or others). When the fresh mortar is spread on the wall, it slowly begins to harden. Hardening of the mortar means the transformation of the slaked lime into calcium carbonate and water, through the reaction of the former with atmospheric carbon dioxide. The aggregates are chemically inert materials and they affect the process only mechanically. The hardening reaction is:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

In fresco painting, it is highly desirable to delay the setting time of the lime plaster, so that the artist has sufficient time margin to work more comfortably.

An attempt to visualize the workable painting time in fresco technique is presented in Figure 12. Experience has highlighted several methods for extending the working window before the plaster sets-such as the use of organic additives-but only up to a point and the specialized use of the trowel to "break" the surface layer of calcium carbonate that forms rapidly, preventing further painting (we shall discuss later for this trowel usage).

Figure 12. *Working time intervals of second lime plaster from the moment of application until drying.*

As shown in Figure 12 if we grade the available time from 1 to 10-from the application of the second lime plaster to its complete surface hardening, at which point painting is no longer possible-the most suitable painting period lies between 7.5 and 8.5. The time blocks shown in Figure 12 are not of equal width, for ease of understanding. In reality, this is not the case.

The first phase, from 1 to 3, does not allow any painting activity, as the surface is excessively watery. During the second phase, from 3 to 5, any painted work is essentially doomed, as water becomes trapped between the plaster and the rapidly forming calcium carbonate layer, leading to the loss of cohesion between the plaster and the painted layer, and eventually to flaking.

Between phases 5 and 7.5, one could attempt to paint, but only with very thick layer of pigments, as the plaster remains quite wet. In the 7.5 to 8.5 phase, the lime plaster is soft and malleable like plasticine; if you mold a small piece between your fingers, it does not stain them. Essentially, this ideal window of time for fresco painting lasts less than 24 hours, even if the whole process takes place over a week.

In the 8.5 to 10 interval, the plaster has dried and become extremely friable; pigments applied during this stage lose their chromatic intensity, take on an earthy texture, and flake off easily the next day.

Within the 7.5 to 8.5 window, painting can be effectively executed using only limewater and pigment, without the need for any organic material. However, if one wishes to paint earlier-between phases 5 and 7.5-an organic binder or combinations of different organic substances are imperative to be added.

The proportion of organics must be small-usually less than 10% by volume of the limewater medium-but sufficient to permit work before the 7.5-8.5 range.

In hardening reaction releases water. The paths through which the water exits from the interior of the mortar to the surface are essentially cracks in the mortar. Cracks also form due to the reduction, the shrinkage of the mortar's volume as it dries. In order to prevent these cracks from reaching an undesirably large width, it is necessary to add materials to the mortar that act as reinforcement. Such natural materials are straw and fibers/hairs. Similar or identical materials have been used since antiquity. In our work, we used two general categories of reinforcing materials: straw from long-stem rye, and thin fibers (from flax or industrial hemp).

3.5. Mortar Reinforcement Materials (Rye Straw, Fine Flax Fibers or Fine Industrial Hemp Fibers)

3.5.1. Long-stem RyeStraw

We prefer rye straw over wheat straw, because rye decays more slowly than wheat, has finer straw, and also has fewer nodes. After cleaning the rye straw from the leaves and the dry flower, it is spread out over a large surface, and little by little, using a sharp tool such as a hatchet, we cut it into pieces of 3-4cm. Subsequently we boil straw pieces for approximately 10-30 minutes in order to soften (as in Figure 13 upper, right). The exact boiling time varies depending on the thickness and hardness of the straw. It is desirable for the straw to soften adequately. The more it softens, the less time the complete mortar (containing all materials) requires to "mature" before use. After draining the boiled straw pieces, we add them to the lime-sand mortar. However, it is necessary for them to remain within the mortar for at least one or two months in order to "bond" with it and soften further.

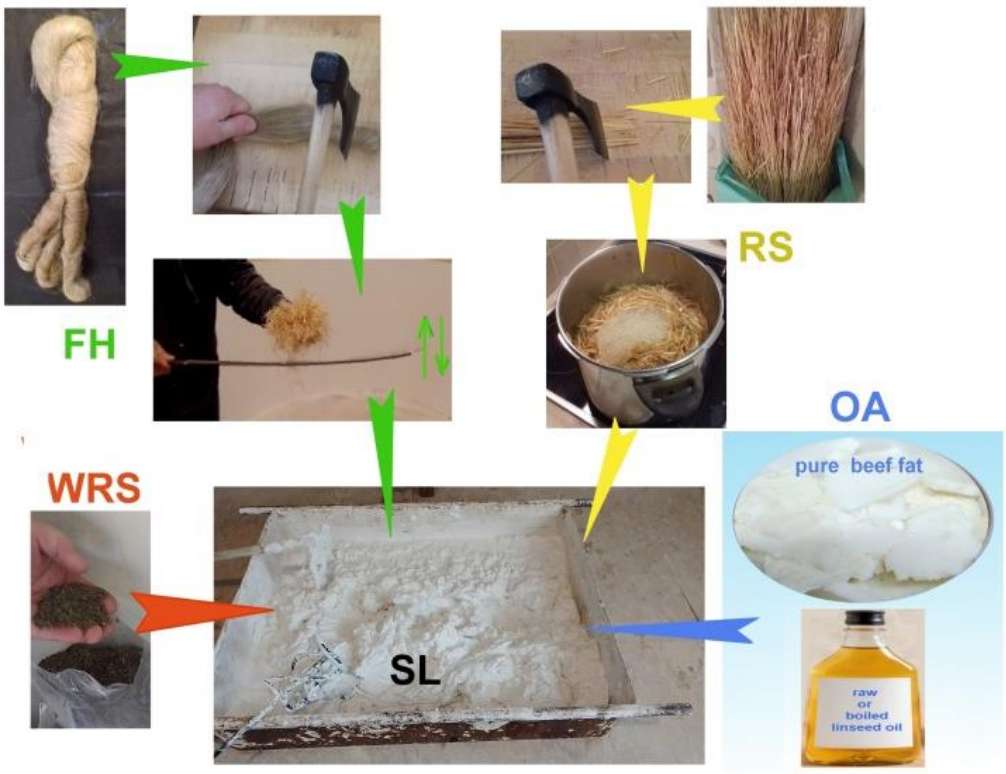

Figure 13. *First plaster layer components: The basic components of the first layer of fresco mortar, known as the BASE (arriccio), are given here. SL denotes aged slaked lime, WRS denotes washed river sand, FH denotes fine fibers of flax or industrial hemp, RS also denotes long-stem rye straw, and OA refers to organic additives. Only two organic materials are shown here (pure soft beef fat or linseed oil) out of the many that have been historically used or that we have used in our frescoes. The flax or hemp fibers FH are untangled, cut to shorter lengths, loosened so as not to form clumps, and evenly dispersed into the mortar. Similarly, the rye straw RS is cut into 2-3cm pieces, boiled for sufficient time to soften, and then added to the mortar.*

Straw, as a plant material, consists mainly of celluloses, hemicelluloses (both of which are polysaccharides) and lignins (which are aromatic compounds polymers). The water in which the straw is boiled, especially after prolonged boiling, is not discarded but used for thinning the mortar, as it contains organic substances (mainly hemicelluloses, etc.). Celluloses and lignins are only slightly to not at all soluble in water but hemicelluloses are partially soluble in water, especially during extended boiling of straw. Specifically, in the boiled straw water, there are also some dissolved sugars (oligosaccharides contained in hemicelluloses, such as arabinoxylans, etc.). In our work on frescoes, we experimentally confirmed that the water dissolved carbohydrates from the boiling of straw improve the performance of lime mortar by enhancing its plasticity, prolonging its drying time, and, at low concentrations, improving its cohesion.

A completely indicative proportion of straw is 5 parts lime mortar (composed of slaked lime and river sand) to 1 part boiled straw, all measured by volume. This ratio may vary between winter and summer. Specifically, a slightly smaller quantity of straw may be required in winter, as there is a reduced likelihood of expansion-contraction and thus cracking, while in summer, a slightly larger quantity of straw than the above may be used.

3.5.2. Fine Flax Fibers, or Fine Industrial Hemp Fibers

As an extra reinforcement material for lime mortars, we use fine fibers of flax or industrial hemp. It is sold in the form of a tuft, which we unfold and cut into pieces of 3-4cm using a sharp tool, such as a hatchet, scissors, etc. After cutting the flax or hemp fibers, we strike the pieces with a long, flexible rod so that they loosen and fluff up like “cotton candy” (as in Figure 13 upper, left). If this is not done to the fibers, when we add them to the mortar, they will form clumps, which is undesirable. The addition to the surface of the mortar is done as if sprinkling salt sparsely on food while simultaneously stirring the mortar. In our work, we do not only use flax fibers that we find on the market in the form of a tuft, but also flax that we cultivate ourselves by sowing flaxseed. However, we will not deal further with that here and will stick to the simple version of commercial flax fibers.

Regarding flax or hemp fibers, an indicative proportion is 3 parts lime mortar (with slaked lime, river sand, and straw) to 1 part flax or hemp fibers that have undergone the “cotton candy” treatment described above. As in the previous case of rye straw, this proportion may be slightly adjusted between winter and summer.

3.6. Preparation of the Wall, Preparation of the Lime Mortars for the Two Plaster Layers of Fresco

3.6.1. Preparing the Wall

The fresco technique depends significantly on the proper preparation of the wall. We remove as much as possible any friable material, previous crumbling plaster, or any old paint, in order to create a stable surface. Subsequently, the wall substrate must be adequately moistened, either by sprinkling or soaking, depending on the requirements. If the wall is stone or marble, lighter wetting is sufficient; if it is brick or made of porous materials, prolonged wetting is necessary due to its significantly higher porosity compared to stone or marble-sometimes for several days prior to painting. A simple empirical rule regarding how many days or how much water should be used for wetting the wall substrate is: in winter, the wall should remain visibly wet for 30 minutes, and in summer for at least 40 minutes.

3.6.2. First Plaster Layer

In Section 1.2 of the introduction, it was stated that lime plaster consists of two layers. Based on our extensive experiments, it was concluded that the first layer, called arriccio or "Basis," is best composed of: i) slaked lime, 3 parts by volume; ii) washed river sand, 1 part by volume; iii) rye straw; and iv) fine fibers (flax or hemp). Both rye straw and fibers can be used simultaneously; if this is not feasible, at least fibers must be used. In this first layer, water retained from boiling the straw may be added, imparting a slight yellow color. This adds organic substances to our mortar, which act as a means of improving its properties. The thickness of the first layer can range from 8 mm up to 1.5cm (Figure 13).

The quantities of rye straw and fibers used, as well as their ratio relative to the other components of the mortar, are not always fixed but are adjusted to prevent intense cracking of the mortar during application to a surface and its drying. This is controlled through samples. Specifically, after adding amounts of straw and fibers, the mortar is mixed, and a sample is spread on a corner of the wall substrate after it hardens. If the resulting cracks are large, additional amounts of straw and fibers are added, and the process is repeated until no visible cracks (discernible to the naked eye) remain (Figure 14).

After numerous tests, it was observed that adding 3-4% boiled linseed oil or 3-4% pure beef tallow (by volume) to the first layer significantly enhances the surface for painting. It prolongs the drying process of the fresco surface and imparts certain plasticity. However, achieving a homogeneous mixture of the fat within the mortar is a challenge. Preliminary findings suggest that tallow performs slightly better than linseed oil.

Figure 14. *A test sample of dried mortar indicating that an additional amount of straw and/or flax and hemp fibers should be added to the fresh mortar, until no visible cracks (discernible to the naked eye) remain (photo from our experiments).*

3.6.3. The Impact of Appropriate Organic Additives in the First Lime Layer on the Overall Quality of the Artwork

A characteristic example of the absence of organic material in monumental fresco painting is shown in Figure 15. In the lower part of a fresco painting by the Astrapades brothers, organic material appears to be missing, in contrast to the rest of the composition. The difference in the vibrancy of the painting is striking: the area without organic additives (lower band) appears visually 'earthy' and feels noticeably rougher and less plastic to the touch.

Figure 15. *From the Crucifixion scene in the Church of Saint Clement, Ohrid-North Macedonia; on-site inspection and photograph by our team. The area without organic additives (lower horizontal band) appears degraded in comparison to the rest of the work, most likely due to the absence of organic additive in the lime plaster.*

Similar observations have emerged through our long-term engagement with fresco painting. The use of organic additives in the first layer of lime plaster significantly enhances the

surface quality, its cohesiveness, and texture. It also extends the working time, as the plaster dries more slowly, providing the fresco painter with additional time.

The organic additives we have used or are still using are the following: starch glue, egg yolk, traces beef bile, sugar, honey, animal fat, linseed oil, and combinations of the above, as well as vinegar and casein. Vinegar and casein did not yield good results in our mortar. In contrast, all the other substances delayed the setting of the first plaster layer to some extent and contributed to its plasticity. The recommended proportion of these setting-retarding organic materials in the mortar should be below 4-5% by volume.

So far, we have concluded that the best results are achieved with raw or boiled linseed oil up to 4% (by volume) and pure beef fat (up to 3% by volume) in the first lime plaster.

It is self-evident that the use and proportion of organic additives should not be indiscriminate or excessive, but should be based on extensive testing and on the study of the few surviving historical references. It is noted that the organic materials to which we refer are those we have tested and whose use has yielded good results.

3.6.4. Second Plaster Layer

The second layer is the surface on which we paint, and we concluded that it should consist of: the face of the final plaster consist of 90 to 95% lime and the remainder of sieved marble powder and quartz sand. Its thickness can reach from 3 mm up to 8 mm.

In this second layer, various organic additives were tested, but it was ultimately concluded that it is better not to include any additional materials.

Once all the materials have been incorporated, the mixture is left to rest for several days to maximize the adhesion of the components, allowing the mixture to "settle," as we call it.

3.7. Application of the Lime Plaster Layers to the Wall, Relative Humidity (RH) and Temperature

3.7.1. Applying the Plaster Layers

Before applying the first plaster layer, we fill the gaps and recesses in the wall substrate to make the surface relatively even using the mortar of first plaster layer.

Next, we apply the first plaster layer, followed by the second. Each layer is spread and leveled using appropriate tools such as a trowel, rubber spatulas, smoothed wooden floats, and others. Each of the two layers requires a suitable and specific amount of time before it is ready for the next step (the first to receive the second, and the second to receive the paint).

3.7.2. Humidity (RH), Temperature

The relative humidity (RH) and ambient temperature during the application of lime mortars can fall within the following ranges. The relative humidity of the environment is ideally between 50-70%. It should be noted that ambient humidity plays a role, but it is not absolutely decisive, as mentioned in Section 3.7 (Preparation of the Wall); the wall must be sufficiently wetted so that it contains the appropriate amount of water internally. Regarding temperature, low temperatures below 5 ℃ are prohibitive. The working temperature can reach up to 40 ℃. With proper management, the work can continue under such high temperatures, but the main issue is the discomfort experienced by the workers. Maybe the major problem is posed by intense and continuous fluctuations in relative humidity and temperature.

3.7.3. Regarding the Water

The water used for wetting the wall and for mixing the mortars must not be “hard,” that is, it must not contain soluble salts. Ideally, it should be deionized (with minimized salt content) or rainwater, provided it has not been collected in areas with significant atmospheric pollution. Otherwise, ordinary potable tap water may be used. This is precisely the practice we follow as well.

3.8. Transferring the Preparatory Drawing on Second Plaster Layer and Paint Layer

Figure 16. *Our team member Emmanouil Kavallaris draws the design onto the fresh lime plaster.*

3.8.1. Transferring the Preparatory Drawing

Once the second layer of plaster has been applied and is still fresh, the preparatory drawing-previously developed through careful study-is positioned on the surface and secured with small nails. Using a pointed tool, such as an empty ballpoint pen, we carefully incise the design by tracing its lines onto the wet plaster. The incised contours are then emphasized with a diluted pigment, typically ochre, to ensure their visibility during the painting process (Figure 16).

We will not go into further detail on this specific topic here, as it may be addressed in a future publication.

3.8.2. Paint Layer

On top of the second plaster layer, the color- paint layers are applied, usually composed of inorganic pigments (and some organo-metallic compounds) mixed with water or preferably limewater. Before proceeding with the painting, it is essential to test the durability of the intended pigments by exposing them to the "harsh alkaline environment" of lime. Only pigments that do not deteriorate can be used in the work.

The paint is prepared by mixing pigment powders with limewater (and, in most cases, a small percentage of organic material-egg yolk, fish glue, casein, etc.-which significantly improve the paint's properties and extend its working time). The painting process then begins directly on the fresh plaster layer. Naturally, the artists had already selected the color tones to be used and tested them on sketches beforehand, to avoid wasting time during the execution of the fresco, since the "clock of plaster freshness" was ticking.

The painting process begins with *stilboma* (στίλβωμα), a trowel scraping technique, which is the pressing of the area to be painted using a trowel in order to break and remove the surface "crust" of lime and prepare the area for color application. This is achieved with specific trowel movements (vertical, horizontal, and oblique) made by applying pressure with the edge of the metal blade, held at a slight angle to the painting surface, almost tangentially to the surface.

When the painted lime plaster dries and solidifies, the pigments become embedded within the forming network of calcium carbonate ($CaCO_3$) molecules-or, alternatively phrased, are bound within the calcium carbonate crystals-and thus become an integral part of the wall. In contrast, in secco painting (dry technique), the pigment grains merely adhere to the dry surface, as if superficially glued rather than embedded in the matrix (this difference is illustrated in Figure 2).

3.9. The Necessity of Organic Additives in the Pigments

The addition of organic substances to the pigments intensifies the colors, imparts certain sheen to the painted surface and simultaneously extends the available working time for painting on the wet render. Our team has used the following among others organic substances as additives in pigments: starch glue, egg yolk, fish glue, gelatin, rabbit glue, casein, goat milk-all with good and interesting results.

Three formulations are presented below, which have perhaps yielded the best results in our work so far.

i) 1 part of Component A and ii) 1 part of Component B, where Component A composed of 1 part egg yolk and 3 parts lime water (by volume) and Component B consists of 1 part fish glue flakes which subsequently are liquefied using the indirect heating method (bain-marie) with 5 parts limewater (by volume).

ii) A very good option is a mixture of only lime water and egg yolk in a ratio of approximately 5% egg yolk to lime water, i.e., 0.5 parts egg yolk with 9.5 parts lime water (by volume). Egg yolk is a very good choice.

iii) 1 part of Component A, ii) 10 parts of Component B (by volume) where Component A composed of 1 part egg yolk and 3 parts lime water (by volume) and Component B composed of 1 part fish glue flakes, which subsequently are liquefied using the indirect heating method (bain-marie) with 7 parts limewater (by volume).

3.10. The Use of the Trowel in Byzantine Fresco Painting and the Evidence for This Use (Trowel Marks)

Figure 17. *Relief inscriptions-notations (which plays the role of a diary) of the organic materials used in the paint while the painting surface was still wet: [upper left: 1 part EGG-ΑΥΓΟ in greek (specifically yolk) and 19 parts LIMEWATER (by volume), upper right EGG-ΑΥΓΟ and GOAT MILK-ΓΑΛΑΚΑΤΣΙΚΑΣ in greek; bottom: FRESCO, SEPTEMBER 2003, 1 part EGG-ΑΥΓΟ and 4 parts LIMEWATER (by volume) + BEEF BILE-ΧΟΛΗΒΟΔΙΟΥ in greek X.B. (6 drops)]. Photos from works by our group.*

In addition to the organic materials added to the first lime plaster layer (arriccio) and to the pigments, we apply an additional technique to extend the period during which the plaster remains functionally wet for fresco painting. The method is as follows: we estimate, for instance, that within

one week we will be able to paint approximately 2 square meters of fresco. Once the application of the second-fine lime plaster (intonaco) is complete, the predesigned sketch is transferred from the paper to the fresh surface (as described above 3.8.1). Very soon, a calcium carbonate crust appears, as a result of the initial setting of the plaster.

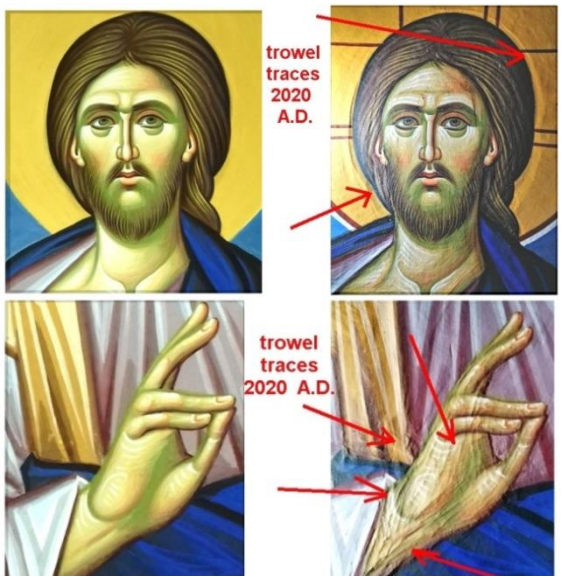

Figure 18. *Trowel traces-marks: All images originate from the same fresco we made in the Church of the Dormition of the Theotokos, Narthex, Glyfada, Attica, Greece (made at 2020 A.D.). The left photographs were taken under direct frontal illumination. The right ones were taken under raking light to reveal the trowel marks. These marks are of exactly the same origin as those observed in the works shown in Figure 8 (This particular work was executed exclusively by the members of our team: Emmanouil Kavallaris, Georgios Tsatsaronis, and Georgios Evangelou).*

The key is not to break this thin calcium carbonate crust in areas where painting cannot immediately proceed. We break the crust using a trowel with a soft blade, making primarily tangential, circular motions over a narrow section. In the area where the trowel passes, the trapped moisture is released. In that specific section, we have approximately two hours of effective working time (Figure 19). Thus, we break the crust only in the portion of the work that we estimate can be completed within two hours.

If drying occurs in less than two hours-something we detect when the pigment ceases to adhere to the plaster and the brush gives the sensation of painting on glass-the trowel is again applied over the painted area (Figure 20A), allowing the pigment to once more bind to the plaster. The marks resulting from this specific use of the trowel are visible in monumental fresco works (Figure 8) and appear identically in the works executed by our team (Figure 18).

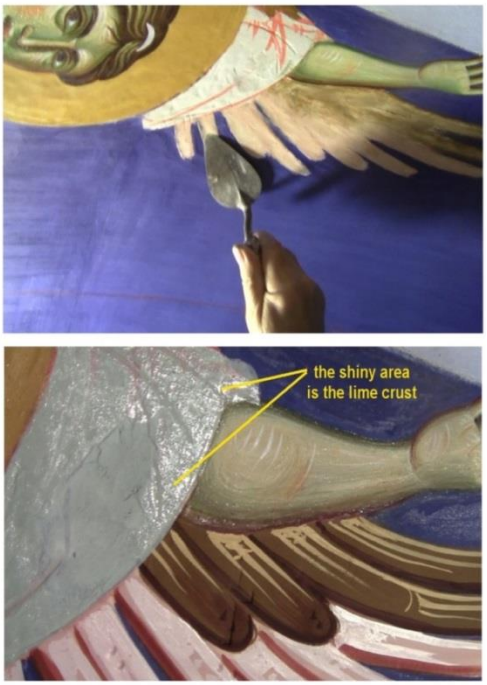

Figure 19. *Trowel in action (from our works, approximately 2015 A.D.). The trowel should break the lime crust that may have formed, so that the color meets fresh plaster and adheres to it. Otherwise, it will flake off or fade within a relatively short period of time as in Figure 1.*

Figure 20. *Sergios Sergiadis and Emmanouil Kavallaris are working side by side on a fresco project (July 2025, Monastery of Saint Ephraim in Attica, Greece). At the top (in A), they break the calcium carbonate crust with the trowel in order to apply the second layer of paint for the green background, and at the bottom (in B), they paint directly onto the fresh lime plaster.*

Once we finish this small section, we proceed to break the crust in the immediately adjacent area that is next for painting. Through this technique, we take advantage of the rapidly forming crust to prolong the effective working time on wet plaster. The thin crust of calcium carbonate, which we do not break immediately, acts as a deterrent to drying, as it traps water within it. This method, however, cannot be sustained over many days. Using all of these techniques, we managed to keep the plaster fresh and receptive to painting for up to one week of work.

4. Results

We have presented the combinations of materials used thus far, some characteristic substance ratios, and the application timelines we have followed, placing emphasis on showcasing those practices that have yielded the most noteworthy results to date. This has been done with the aim of promoting the use of fresco painting, in the Byzantine manner, as a dynamic practice in everyday artistic production-both for the exceptional durability of the works and for the quality of the chromatic layers. There are many more details; however, including them would exceed the length limits set by the journal.

5. Discussion

The maximum effective working time we have achieved while maintaining the plaster functionally wet is approximately 3 weeks (20 days) [31] (at time interval 5:56- 6.02 min). However, this does not usually occur. The maximum typical optimal duration is one week.

Maybe the old masters may have achieved even longer durations. One of our next goals is to find ways to extend this one-week period even further.

Additionally, the experiments we conducted-using organic additives-for the preservation of frescoes in outdoor settings resulted in works that remained durable for one decade. However, the challenge posed by churches painted on their exterior surfaces and enduring for at least 400 years (as seen in Northeastern Romania) serves as a reminder that we still have much to explore and test. It is very likely that the old craftsmen possessed additional secrets. However, serious consideration must be given to the sunshine and the specific Mediterranean climatic conditions of Greece in comparison to the more humid and less sunny climates of the North.

Our work is governed by a guiding principle, which carries demanding consequences. Used materials, their combinations, including organic additives, their mixing ratios, are numerous, rendering our work essentially a continuous experiment. Some of the collaborators of Sergiadis Sergios have often pointed out the necessity of bringing this ongoing search to a pause and of adopting the combinations that have already yielded the best results, since, beyond continuous research, the work also has a subsistence function. Put simply, the constant experimentation reduces the available professional time needed for livelihood. Nevertheless, Sergiadis Sergios has so far remained steadfast in this principle, strongly urging his collaborators to remain committed to this unending pursuit, and inspiring them to uphold this principle.

The prerequisites that must be strictly observed in order to achieve a "successful" fresco painting, as experimentally confirmed by our fresco painting team, with regard to materials, are as follows:

1. Well-slaked lime, achieved by storing it in water for at least six months. The lime should be rich in calcium and contain as few impurities as possible, such as magnesium compounds or other substances.
2. Clean sand, free from clay (soil) particles and greasy substances, washed and dry, preferably river sand.
3. Water containing minimal soluble salts, chlorides, sulfides, sulfates, and others.
4. Plaster reinforcement materials, carefully processed, such as straw (preferably rye straw) and diluted flax or industrial hemp fibers.
5. Marble dust.
6. Organic additives, generally in proportions below 10% by volume (e.g., egg yolk, starch glue, fish glue, rabbit glue, casein, fat-preferably beef tallow for its higher purity-linseed oil, etc.).

Straw, fibers, and organic additives are added to the first layer of lime plaster and are avoided in the second and final layer.

The paints are prepared using limewater, alkali-resistant pigments, and organic additives in proportions up to approximately 10%. The presence of organic substances in both the plaster and the paint imparts plasticity, improved texture, better cohesion, a delicate sheen, and greater durability. It also extends the working time, keeping the plaster moist and receptive to the pigments for longer.

As indicative of the experiments we conducted to assess the impact of organic additives on the durability of works, Figure 21 is provided. It appears that the organic component, act as a water-repellent in the paint, preventing the penetration of atmospheric moisture. In the same direction of highlighting the effect of organic additives is Figure 15, depicting a monumental fresco by the Astrapades brothers in North Macedonia.

Although many materials have been tested, the most effective appear to be linseed oil or beef tallow (up to 4% by volume in the first plaster layer), and egg yolk and/or fish glue.

The first plaster layer should be thick (approximately 1-2cm), with a lime-to-aggregate ratio of 3:1 by volume. The second layer should be thinner (approximately 0.6cm), with a lime-to-aggregate ratio of 9:1.

The paints must be dense. Wherever the plaster dries (i.e., forms a calcium carbonate crust) during the painting process, it is broken with the trowel, and the work continues.

More precise ratios and any issues encountered may be addressed in a future, more technically oriented publication. It

is possible that a comprehensive monograph in the future may address a much broader range of technical details of our work.

With the specifications we employed (some of which could not be described due to the limited length of the article), we obtained the experimental results mentioned. If somebody applies only parts of what has been described, we cannot guarantee that the same results will be achieved.

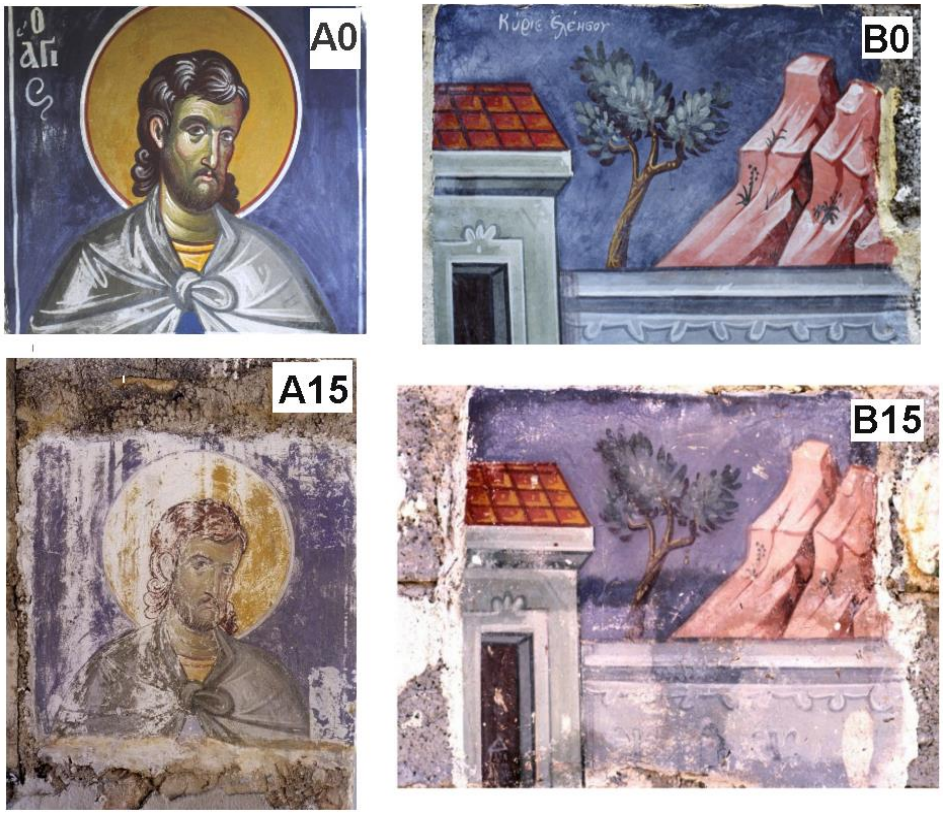

Figure 21. *The two experimental fresco works (A and B) were executed on an exterior wall with a western orientation (exposed to intense sunlight during the summer months and pronounced humidity and cold during the winter) on the slopes of Mount Pentelicus in Attica, where the Holy Monastery of Saint Ephraim is located. Both works were created during the same time period (2000 AD). In Work A, no organic additive was used, whereas in Work B, casein organic additive was applied. During the first 10 years, both remained fairly stable. In the subsequent 5 years, that is, 15 years after their creation, Work B is evidently in better condition. The deterioration in the work without organic material is evidently more intense. Work A may be considered as a control sample regarding the effectiveness of organic additives. Another relevant example from monumental fresco painting is shown in Figure 15 (from a work by the Astrapades brothers), where the lower horizontal zone appears to have been executed without the addition of organic material, in contrast to the rest of the work.*

6. Conclusions

Byzantine Fresco technique offers exceptional durability of the work and superior quality of the chromatic layers.

Through the parallel study of the limited bibliographic references, continuous experimentation, persistent effort, investigation of materials, and the observation of monumental fresco works in situ, we have succeeded in producing noteworthy fresco paintings in the Byzantine manner.

We encourage other artists but simultaneously strive to extend in the future the working time for painting on wet lime plaster, from one week, which is our usual, to a significantly longer period.

We also attempt to produce as many of the materials we use as possible through our own production, as we do with the preparation of fat directly from purchased meat, the cultivation of flax and rye from our own crops, and the construction of the necessary wooden scaffolding.

Our findings are disseminated through conferences, publications, and lectures, with the aim of inspiring artists to integrate fresco painting into their practice so that this laborious, yet genuinely durable and coherent technique is not lost.

Abbreviations

AD	Anno Domini
BC	Before Christ
FH	Fine Fibers of Flax or Industrial Hemp

IR	Infra Red
OA	Organic Additives
RS	Rye Straw
SL	Slaked Lime
WRS	Washed River Sand
XRF	X- ray Fluorescence

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Alongside the authors, the following individuals are valued members of our Fresco Team: Georgios Tsatsaronis (Painter, Fresco artist, graduate in Mathematics from the National and Kapodistrian University of Athens), Georgios Evangelou (Painter, Fresco artist, Head of the technical division of our team, graduate in History from the National and Kapodistrian University of Athens), Stavros Kavallaris (Painter, Fresco artist, graduate Conservator of Works of Art from the University of West Attica), Christos Tsatsaronis (Painter, Fresco artist, undergraduate Physics student at the National and Kapodistrian University of Athens), Panagiotis Kotsalas (Painter, Fresco artist, graduate of the Athens University of Economics and Business, Department of Marketing), Aikaterini Roussou (Philologist, Archaeologist, graduate of the National and Kapodistrian University of Athens). Also the newer members EvaggelosVardavakis ((Painter, Fresco artist) and Ilias Kanavos (Painter, Fresco artist).

Author Contributions

Emmanouil Kavallaris: Writing - original draft, Investigation, Methodology, Data curation

Sergios Sergiadis: Project administration, Supervision, Methodology

Ioannis P. Kotsalas: Writing - review & editing, Data curation

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Chatzidakis, M. (1997). The Cretan Painter Theophanis - The Wall-Paintings of the Holy Monastery of Stavronikita. Holy Monastery of Stavronikita, Holy Mountain (Agion Oros).

[2] Sergiadis, S., Karagiannis, N., & Kotsalas, I. (2016). Research Gate. Retrieved 06 14, 2025, from https://www.researchgate.net/publication/313844359_Byzantine_Painting_Fresco_or_PersistentlyObstinately_Secco

[3] Sergiadis, S., Karagiannis, N., & Kotsalas, I. P. (2016). Byzantine Painting: Fresco or (Persistently)/Obstinately Secco? 2nd International Meeting for Conservation & Documentation of Ecclesiastical Artefacts (pp. 236-244). Ithaki Island, Greece: Balkan Heritage Foundation.

[4] Vitruvius, P. (1999). The ten book on architecture,. (I. D. Rowland, Trans.) Cambridge, UK: Cambridge University Press.

[5] Oktaviana, A. A., Joannes-Boyau, R., Hakim, B., & al., e. (2024). Narrative cave art in Indonesia by 51,200 years ago. Nature, 631, 814-818.

[6] Hood, S. (1984). A Minoan Empire in the Aegean in the 16th and 15th Centuries B.C. Minoan Thalassocracy, Third International Sumposium of the Swedish Institute in Athens, (pp. 33 - 37.).

[7] Higgins, R. (1981). Minoan and Mycenaean Art. New York and Toronto: Oxford University Press.

[8] Lydakis, S. (2002). Ancient Greek Painting. Melissa Publishing House.

[9] Doumas, C. (1992). The wall paintings of Thera. The Thera Foundation Petros M. Nomikos.

[10] Plantzos, D. (2018). The Art of Painting in the Ancient Greek World. Athens: Kapon Editions.

[11] Mayer, R. (1982). Handbook of Materials and Techniques. The Viking Press.

[12] Talbot-Rice, D. (1994). Byzantine Art. Athens: Ypodomi Editions.

[13] Paliouras, A. (2000). Introduction to Byzantine Archaeology. Ioannina: University of Ioannina.

[14] Labatt, A. (2004, 10 01). Frescoes and Wall Painting in Late Byzantine Art. Retrieved 06 15, 2025, from https://www.metmuseum.org/essays/frescoes-and-wall-painting-in-late-byzantine-art

[15] Dionysius, P. (1900). Interpretation of Byzantine Painting Art, (from an 18th-century manuscript publishewith a modern reprint by Spanou Publications. A. Papadopoulos-Kerameus.

[16] Achemastou-Potamianou, M. (1994). Byzantine wall-paintings. Athens: Ekdotiki Athinon.

[17] Kontoglou, P. (1979). Expression of Orthodox Iconography. Athens: Astir.

[18] Darling, J. (2004). Architecture of Greece. Greenwood Publishing Group.

[19] James, L. (2010). A Companion to Byzantium. John Wiley & Sons.

[20] Danoussis, K. (2004). The Iconographer Georgios Markou from Argos. Argos, Greece: Scientific and Literary Publication of the Cultural Center of the Municipality of Argiaki Land.

[21] Rossi, M. A., & Sullivan, A. I. (Eds.). (2024). The Routledge Handbook of Byzantine Visual Culture in the Danube Regions, 1300-1600. Routledge.

[22] Kavallaris, S. (2023, 7 13). Technology and conservation issues of contemporary wall paintings with fresco technique: study and documentation of wall paintings of the artist Sergios Sergiadis. Retrieved 06 18, 2025, from https://polynoe.lib.uniwa.gr/xmlui/handle/11400/5039

[23] Mastrotheodoros, G., Anagnostopoulos, D., Filippaki, E., Beltsios, K., Bassiakos, Y. (2019). Probing the birthplace of the "Epirus/NW Greece School" of painting: analytical investigation of the Filanthropinon monastery murals. Part II: non-pigment materials and painting technique. Archaeological and Anthropological Sciences. 11. https://doi.org/10.1007/s12520-019-00905-5

[24] Orlenko, M., Ivashko, Y., Ding, Y. (2022). Fresco wall painting and its regional modifications. International Journal of Conservation Science, 13(1), 57-72.

[25] Jiménez-Desmond, D., Pozo-Antonio, J. S., Arizzi, A. (2024). The fresco wall painting techniques in the Mediterranean area from Antiquity to the present: A review. Journal of Cultural Heritage, 66, pp. 166-186.

[26] Art News & Views (2025, 19 7). The Revival of Fresco Painting in Contemporary Architecture. Retrieved 08 12, 2025, from https://artnewsnviews.com/design-architecture/modern-fresco-revival

[27] Baiandin, S., Ivashko, Y., Dmytrenko, A., Bulakh, I., Hryniewicz, M. (2022). Use of historical painting concepts by modern methods in restoration of architectural monuments. International Journal of Conservation Science, 13(2), pp. 381-394.

[28] Mora Rivas, M. (2024). Engineering a Masterpiece: The Science of Fresco Painting. USC Viterbi Illumin (Engineering Journal), XXIV (III), Retrieved 8 13, 2025, from https://illumin.usc.edu/engineering-a-masterpiece-the-science-of-fresco-painting

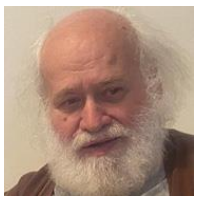
[29] Novak, M., Ormsby, B. (2023). Poly (Vinyl Acetate) Paints: A Literature Review of Material Properties, Ageing Characteristics, and Conservation Challenges. Polymers, 15(22), 4348. https://doi.org/10.3390/polym15224348

[30] Jablonski, E., Learner, T., Hayes, J., Golden, M. The Conservation of Acrylic Emulsion Paintings: A Literature Review. Retrieved 08 12, 2025, from https://www.researchgate.net/publication/260400209_The_Conservation_of_Acrylic_Emulsion_Paintings_A_Literature_Review

[31] Segiadis, S., Karagiannis, N., & Kotsalas, I. (2016, 12 13). CENTER FOR THE STUDY OF BYZANTINE PAINTING AND ICONOGRAPHY. Retrieved 8 3, 2025, from https://www.youtube.com/watch?v=h46Rn0fZQa8&t=271s

Biography

Kavallaris Emmamouil is an accomplished iconographer with over 30 years of experience in traditional Orthodox Byzantine Iconography and Fresco wall paintings in the Orthodox, Byzantine way. Lead master Iconographer and Iconography Instructor at Holy Archangels Greek Orthodox Monastery, Kendalia, TX, USA: October 2017-December 2019, May 2022-present. Kavallaris Emmanouil acquired extensive expertise on the specialized Frescotechnique by the iconographer Sergios Sergiadis..It is important to note that very few iconographers have mastered this technique even in countries where iconography has been practiced for thousands of years (2000 B.C.), e.g., Greece. Kavallaris Emmanouil continues to collaborate with Sergios Sergiadis in Greece until the present. He is also a member of the Chamber of Fine Arts of Greece. He has authored peer-reviewed publication in scientific journal.



Sergiadis Sergios is a Master Fresco painter and researcher. Trained under Nikolaos Stratoulis and Romanian brothers Morosan (Mihai and Gabriel). He has worked independently since 1973 and specialized in traditional Byzantine Fresco painting since 1986. His work includes major projects across Greece and Cyprus. In parallel, he conducts systematic research on the materials, chemistry, and issues concerning fresco painting, collaborating with institutions such as Archaeometry Laboratory at the National Centre for Scientific Research "Demokritos", in Athens, Institute of Geology and Mineral Exploration in Athens and the Ormylia Foundation Diagnostic Centre (Halkidiki). He has also visited mining sites for the study of natural pigments. He is a member of the Chamber of Fine Arts of Greece. He has studied historic frescoes in Mount Athos, Meteora, Mystras, Balkans, Sinai, and the UK. He leads a team of iconographers and he has authored peer-reviewed publications and participation in many international and Greek conferences.

Kotsalas Ioannis is a Faculty member at Ecclesiastical Academy of Athens, Management of Ecclesiastical Cultural Heritage Objects Program. He holds two doctoral degrees. PhD in Physics from School of Applied Mathematical and Physical Sciences, National and technical University of Athens and PhD in Environmental Chemistry and Sustainable Development Education from National and Kapodistrian University of Athens, Department of Chemistry. Indicative teaching subjects: *Physicochemical Methods for the Diagnosis of Relics, Intervention and Restoration Materials, Causes and Mechanisms of Material Degradation, Science and Technology of Materials for making religious Artifacts.* Since 2000, he has been an icon painter and is a member of Sergios Sergiadis's Fresco Team. He is also a member of the Chamber of Fine Arts of Greece. He has authored peer-reviewed publications in scientific journals and has contributed to academic monographs.