JOURNAL OF DESIGN FOR RESILIENCE
IN ARCHITECTURE & PLANNING

Research Article
Online: www.drarch.org
Volume 6, Issue 2 (273-289), 2025
DOI: 10.47818/DRArch.2025.v6i2168

A non-destructive testing method for the production technique of gilded ornamentation in a traditional house: XRF analysis method

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Abstract

Gold, with its thousands of years of history, has been used across different geographies and with various techniques, carrying diverse meanings beyond being just a metal. Similarly, a variety of techniques can be observed in the production of gold imitation. In cultural heritage buildings, determining whether such ornaments are made of real gold and identifying the production technique are crucial for making correct decisions in restoration. The knowledge and experience of craftsmen can be utilized to determine the content and production technique of the ornamentation in a cultural heritage building; however, this empirical approach is unscientific and prone to error. This study is unique and valuable as it provides information based on definitive results through an analytical and scientific approach. The material of this study is a gilded ornamentation from a traditional house in Sivas. XRF (X-rays fluorescence) analysis method was employed to understand the elemental analysis and production technique of gilded ornamentation. The aim of this study is to determine both the production technique and the elemental structure of the material through XRF analysis of the gilded ornamentation. The absence of gold in the analysis indicates that the gilding was not produced from original gold but is an imitation. When evaluating the gilding imitation techniques, the concentration of copper and zinc elements indicates that the imitation gilding was produced from a brass alloy. The zinc/copper ratio was found to match the ratio used to achieve a gold-like color. Additionally, when other techniques used for gold imitation were evaluated, the absence or trace amounts of other elements excluded those techniques. Consequently, this study presents a new approach to the literature by demonstrating the applicability of modern, non-destructive, contactless techniques like XRF analysis to the science of conservation and restoration.

Keywords: gilding, gilding imitation, gold, NDT, XRF analysis

1. Introduction

In addition to its resistance to atmospheric conditions, oxidation-induced corrosion, galvanic wear, and chemicals, gold's ease of workmanship and its rarity compared to other metals have conferred upon it the symbolic meanings of "value," such as power and wealth. These symbolic attributes have sometimes even made gold a central element in religious ceremonies. The diverse meanings attributed to gold, beyond being merely a metal, have influenced its widespread use across vast geographies, from Europe to Mesopotamia, Egypt to Russia, and even the Far East (Pliny the Elder, Liber XXXIII, i-1, Franklin, 1995; Figueiredo et al., 2010; Klemm & Klemm, 2012; Fomicheva & Valuev, 2021; Ryu, 2022; Miho, 2022; Ulak, 2023).

The term 'gilding' refers to the process of coating an object with gold, either in liquid form or as gold leaf, or with a similar material to give the impression that it is made of or covered with gold. Gilding can also be produced using silver and copper alloys (Sözen & Tanyeli, 1994; Hasol, 2005; Britannica, 2016; Oxford, 2024; TDK, 2024). It can be stated that the use of gilding has persisted from the Bronze Age to the present day. In its early applications, gilding primarily involved directly covering the surfaces of non-gold objects or architectural elements with gold (Pliny the Elder, Liber

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Article history: Received 06 September 2024, Revised 15 April 2025, Accepted 02 June 2025, Published 30 August 2025

XXXIII, xviii-55; Kalter, 1985; Oddy, 1993; Figueiredo et al., 2010; Klemm & Klemm, 2012; Oktay, 2013).

The earliest examples of gilding, observed around 3000 BCE in the Middle East, are known to have been produced by mechanically securing a thick layer of gold leaf onto the underlying substrate (Figures 1-2). In this method, known as gold leaf gilding, the leaf is pressed and riveted onto the substrate, its edges are folded, or it is placed into a fine groove cut into the surface. By 2000 BCE, gold had been refined and further thinned by hammering. This technique, referred to as leaf gilding, involves the application of an organic adhesive to the underlying substrate or the preparation of a calcite/gypsum ground as an intermediate layer, onto which the thin leaf is applied. Another technique known to have been used since around 1200 BCE is the diffusion bonding technique. In this method, gold and the underlying metal layer are heated together, creating a stronger bond between the two metals through diffusion than with mechanical fastening. While this technique forms a good bond with silver, it is not suitable for use with metals such as tin and lead, which have low melting points (Nicholson, 1979; Oddy, 1981; Oddy, 1993; Oddy, 1995; Figueiredo et al., 2010).

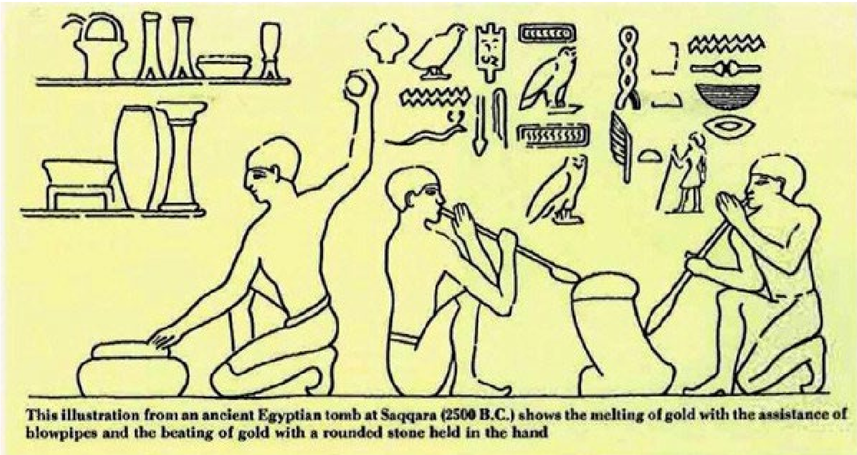

Figure 1 An image found in a tomb in Ancient Egypt from around 2500 BCE: The thinning of gold by hammering (Nicholson, 1979)

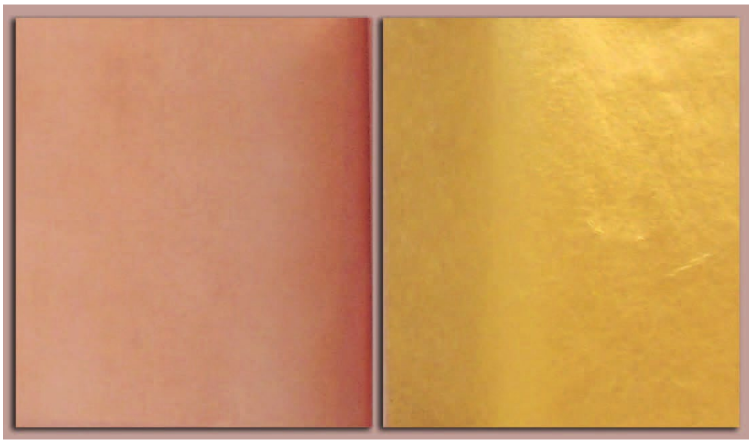

Figure 2 Example of gold leaf (Önel, 2016)

In the 4th century BCE, a new technique was developed in China where gold was combined with mercury amalgam, allowing the mercury to adhere the gold to the surface. In this technique, the mercury-gold amalgam is applied to a previously cleaned surface. The object is then heated (to approximately 365°C) until the mercury evaporates. As the mercury vaporizes, the gold adheres to the surface and is then polished. This technique, known as fire gilding (amalgam gilding, mercury gilding, tombac), became widespread in China during the 3rd century BCE and later spread to Rome and, through Rome, to Europe in the 1st and 2nd centuries CE (Pliny the Elder, Liber XXXIII, xx-64, XLii-125; Oddy, 1993; Anheuser, 1997; Figueiredo et al., 2010; Darque-Ceretti et al., 2013; Britannica, 2016; Önel, 2016; Ortega-Feliu et al., 2017). In addition to this technique, a mixture of honey and gold can also be applied with heat to adhere gold to the surface; however, honey tends to dull the gilding (Balıkçı, 2007). Besides the hot application methods mentioned above, there are also cold application techniques where mercury is used as an adhesive for gold leaf (Darque-Ceretti et al., 2013; Ingo et al., 2013). Another cold application technique involves applying gold in liquid form to the surface using a brush. To provide protection, linseed oil can be applied over the gilding, although this method may cause the gilding to peel off from the surface (Balıkçı, 2007).

Another technique to mention is the gouache gilding (water gilding) method, where gold leaf is adhered using red bole[1]. This technique, which became widespread in the Middle Ages, involves placing a moistened leaf onto a base layer made by mixing bole or red-orange pigments containing lead oxide with animal glue. There are also examples where the leaf is placed on a well-smoothed mixture of glue and gypsum without the use of bole (Hradil et al., 2003; Gulotta et al., 2012). In gouache gilding, it is known that binders such as rabbit skin glue and egg yolk were also used (Toniolo et al., 1998; Gulotta et al., 2012; Brocchieri et al., 2022a; Saggio et al., 2023). In mordant gilding (oil gilding), more durable and higher adhesion applications were achieved by using certain stabilizers such as linseed oil, mineral fillers, and lead white (Gulotta et al., 2012; Steger et al., 2021).

Gold powder gilding is a technique used in China since around 1000 CE, where gold powder is mixed into a binder to create the gilding material (Darque-Ceretti & Aucouturier, 2013). This method involves crushing gold leaf or foil with Arabic gum and applying the resulting fluid mixture to the surface with a brush (Önel, 2016). With technological advancements, fine gold obtained through chemical precipitation from gold-containing compounds is now also used for decorative painting purposes (Darque-Ceretti & Aucouturier, 2013). Another method involves dipping linen into a gold chloride solution, drying and burning the linen, and then transferring the gold flakes that have fallen off to another layer with the help of a leather tool (Oddy, 1995).

Depletion gilding is a technique discovered in the early years of Christianity in Europe and in the same period in Central and South America. It involves the use of chemicals to dissolve other metals in a gold alloy, thereby purifying the gold and using it to gild another object (Bray, 1993; Darque-Ceretti & Aucouturier, 2013). In the 19th century, these techniques were further developed with the introduction of electroplating (Oddy, 1993; Anheuser, 1997; Ortega-Feliu et al., 2017).

Gilding can be produced directly from gold, but gold imitation can also be made from other alloys (Darque-Ceretti & Aucouturier, 2013; Simsek et al., 2015). Copper and zinc alloys (brass) are commonly used for gold imitation due to their cost-effectiveness (Cession, 1990; Scott et al., 2007; Miliani et al., 2009; Sandu et al., 2011a; Gulotta et al., 2012; Simsek et al., 2015; Marchetti et al., 2023). The earliest use of brass, dating back to 4700-4000 BCE in China, was as gold-colored leaf, with similar uses in England around 3000-2000 BCE, in the Middle East around 2000 BCE, and in Anatolia around 1000 BCE (Craddock, 1978; Craddock et al., 2004; Fan et al., 2012; Wei et al., 2022). To achieve a color close to 22-karat gold, the zinc/copper ratio should be approximately 1/5 to 1/6 (14/86). Increasing the zinc content in this alloy, also known as Dutch metal, will whiten the color of the metal. Conversely, decreasing the zinc content will produce a color range from pale gold to reddish pale gold (Britannica, 1998; Craddock et al., 2004; Thornton, 2007; Duran et al., 2008; Steger et al., 2021; Parma et al., 2023).

In addition to using alloys of less valuable metals such as copper and zinc (sometimes lead and tin) in leaf form for gilding imitation, there are also applications of powdered purpurino (porporina)[2] in gilding with gold powder (Duran et al., 2008; Sansonetti et al., 2010; Sandu et al., 2011a; Lalli & Innocenti, 2016). This technique, which involves mixing powders obtained by finely

[1]Bole is fine-grained, velvety red clay used for adhering gold leaf or as a ground layer, composed of natural ferruginous alumina silicates, oils, and other minerals. White bole is a type of China clay made from kaolin (Hradil et al., 2003; Gettens & Stout, 2012).
[2]Purpurino is a yellow metal powder used for gilding imitation (Brocchieri et al., 2022a).

grinding brass leaves or foils with a resin solution and applying it to the surface, was used in the 12th century and is still in use today (Thornton, 1995; Sandu et al., 2011a).

In the 13th and 14th centuries, powdered tin sulfide was also used for gold imitation gilding. This technique, known as mosaic gold, involves heating tin, mercury, and sulfur to different temperatures to achieve yellow hues. Because mosaic gold is unstable and toxic, it was replaced in the mid-18th century by brass powders. Brass, which resembles gold and is finely granulated, became preferable to other copper-based alloys. With the invention of a mill for grinding metal foils in the 19th century, the popularity of metal powders increased further by the mid-century (Duran et al., 2008; Gulotta et al., 2012; Steger et al., 2021; Brocchieri et al., 2022a). Additionally, brass powder paint is used not only for imitation gilding but also occasionally applied over a gold layer (Risdonne et al., 2018).

Another gilding imitation method involves painting silver or tin leaf with yellow varnish (known as the Mecca technique). To make tin leaf resemble gold leaf, a mixture of hydrocerussite, lead oxide, and beeswax was used. Silver, however, tends to tarnish due to oxidation, limiting its use (Mayer, 1951; Thornton, 1995; Fiorin & Vigato, 2007; Duran et al., 2008; Sansonetti et al., 2010; Sandu et al., 2011a; Sandu et al., 2011b; Gulotta et al., 2012). Additionally, gilding imitation has been achieved by painting white metals like lead and polished iron with yellow-orange varnish. There have also been attempts to achieve gold-like brightness using techniques such as sulfidation of silver. Another process, known as anodization, has been used to produce stable and bright-colored oxide layers on metals like aluminum, titanium, and niobium, serving as a gilding imitation. Gilding imitation through vapor deposition and gilded paint production with mica-based bright pigments are also present (Thornton, 1995).

The gilding techniques mentioned above have historically been employed in cultural heritage structures, either using real gold or gold imitations. Attempting to identify the original gilding technique during restoration based solely on personal experience or intuition is prone to human error and may lead to restoration practices that are not faithful to the original.

This study aims to propose a method for identifying the original production technique of a decorative element used for ornamentation in a cultural heritage structure. Within the scope of the study, it was first aimed to determine whether the gilded decoration was produced using real gold or a gold imitation by applying a non-destructive testing method. For this purpose, the XRF (X-rays fluorescence) analysis method was employed to characterize the elemental composition of the gilding. Additionally, a literature review was conducted to investigate traditional gilding production techniques. The data obtained from the XRF analysis were then compared with the traditional gilding techniques identified in the literature, enabling the determination of the original production technique used for the decoration in the examined house.

The material of the study is a gilded decoration located on the wall of a traditional house in Sivas. As the study aims to propose a method for identifying original production techniques, a single case study was selected, thus defining the study's scope and limitations. Expanding the sample to include gilded decorations from different buildings was not feasible due to time constraints and the limitations of the article format.

Based on the elemental composition identified through XRF analysis, certain traditional techniques that could not have been used were eliminated, thereby enabling the identification of the original gilding technique applied to the decoration.

2. Material and Method

The gilded ornamentation that constitutes the material of this study is from a traditional house located at layout 160, block 103, plot 1 in Akdeğirmen Neighborhood, Sivas city center, an area known for its dense concentration of registered traditional houses (Figure 3) (Tapu, 2024).

The house, registered by the Kayseri Cultural Heritage Protection Board with decision number 851 dated October 20, 1990, was later protected by the Sivas Cultural and Natural Heritage Protection Board with decision number 1298 dated July 20, 2009, along with blocks 103, 104, 106, 110, and 114 (Vural, 2018).

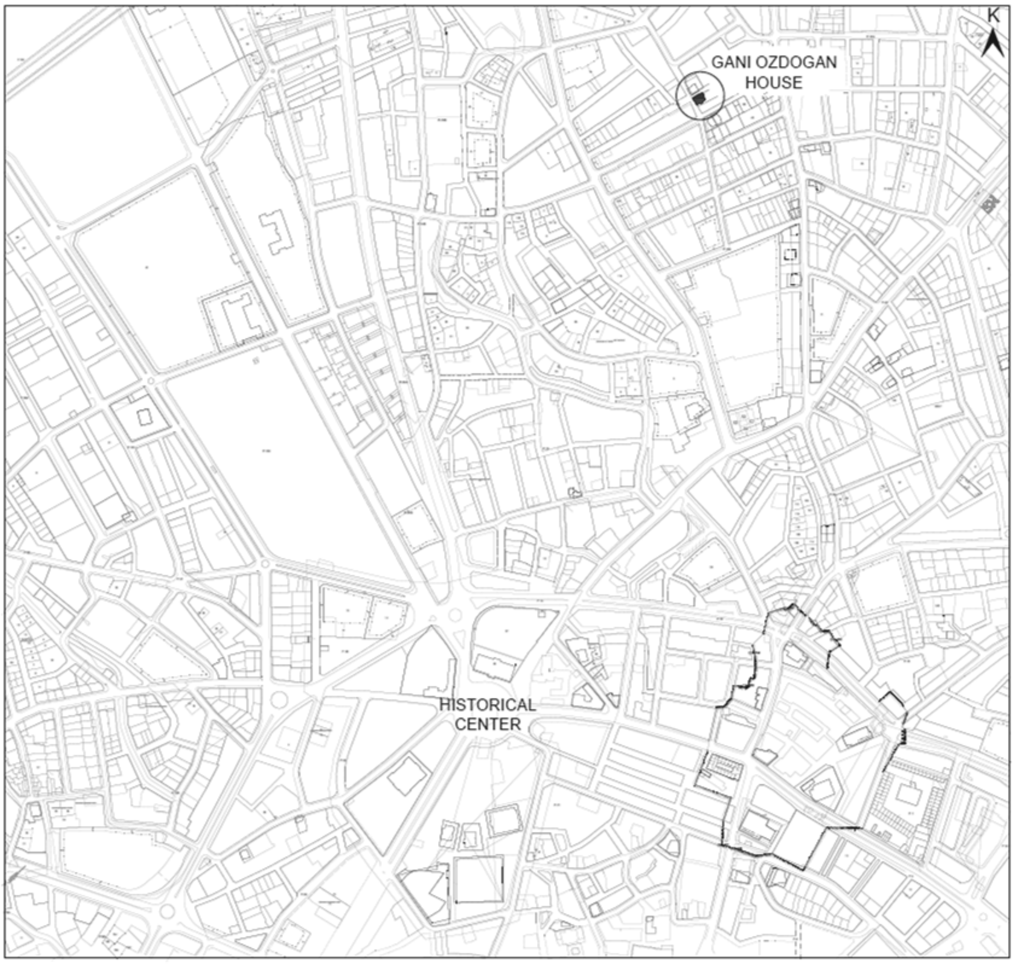

Figure 3 Urban location of Gani Ozdogan house (Sivas Belediyesi Arşivi, 2019)

Figure 4 South facade (Vural, 2018)

The entrance to the house's garden is from 18-Dispanser Street, while the main entrance is recessed into the south facade, positioned between wooden columns. The southern facade is more ornate than the others, featuring an inscription on the gable of the semi-hexagonal bay window (Figure 4). The inscription indicates that the house was constructed in the 19th century and reflects the influences of Westernization Period Ottoman Architecture. The house, with a typical plan, consists of a basement, ground floor, and first floor. The roof is a gabled roof with mission tiles and has broad eaves. The basement is made of stone masonry, while the upper floors are constructed with timber framing and mud brick infill, finished with plaster. Other facades of the house also feature projections, including a small, semi-hexagonal oriel on the north facade facing 18-13 Street. The facades display wooden moldings and profiled columns.

The basement, constructed of rubble stone, consists of a single space formed by floor beams resting on wooden posts and walls. On the ground floor, there are four rooms radiating from the central hall (sofa) and an additional bathroom. The first floor also has four rooms opening to the central hall, along with a modern kitchen and WC (Figure 5) (Vural, 2018). The gilded ornamentation under study is located in the room on the upper floor facing south and west (Figure 5). Above the built-in cupboard and niche, designed along with the northern wall of this room, there is a gilded decoration. This decoration consists of acanthus leaves emerging from a vase and symmetrically arranged floral rosettes filling the spaces created by the leaves as they curve downward (Figure 6). The gilded decoration being studied was made on a lime-plastered wall.

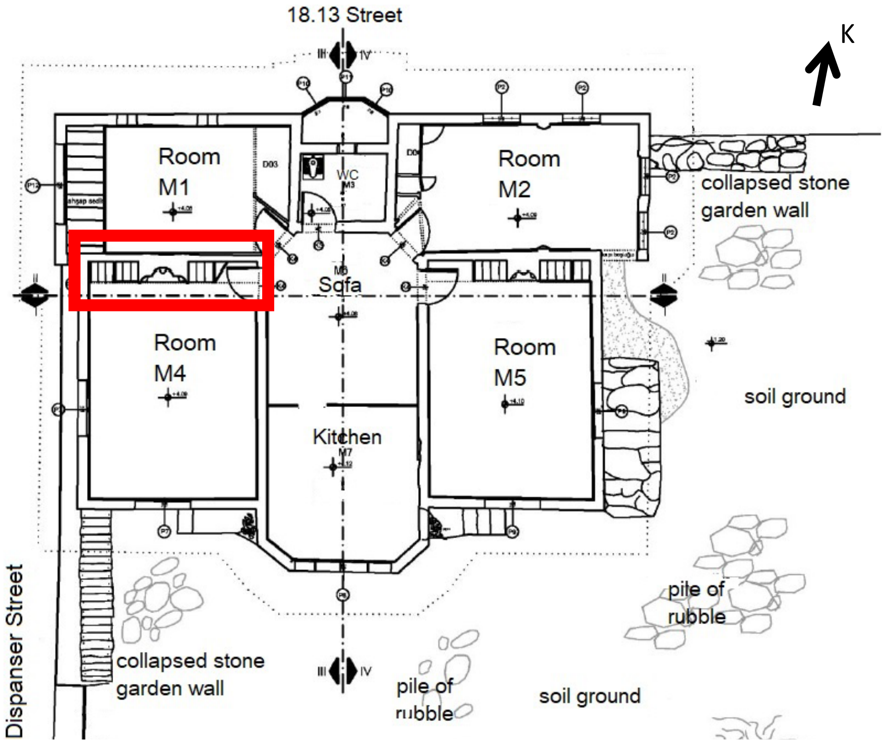

Figure 5 First floor plan of the house (Vural, 2018)

Figure 6 The gilded decoration on the wall of the southwest room (Vural, 2018)

Understanding traditional production techniques of gilded decorations is valuable for preserving traditions, passing them on to future generations, and providing architects with insights into proper restoration practices using traditional methods. Scientifically determining which traditional production techniques were employed in a gilded decoration within a cultural heritage site enables informed decision-making during the restoration process.

Scanning electron microscope (SEM), energy dispersive spectroscopy (EDS), certain applications of Fourier-transform infrared spectroscopy (FTIR), and Raman spectroscopy used for the characterization of gildings cause minor damage to the cultural heritage structure since they require sampling. The use of these methods, which are considered destructive, constitutes an invasive intervention. Therefore, within the scope of this article, a more conservation-oriented approach was adopted, and the non-invasive, non-destructive XRF method was preferred.

2.1. Theoretical Basis of the Methods

Portable XRF devices are portable spectrographs that measure the secondary fluorescence X-rays produced when atoms in a material are excited by X-rays emitted from the device, causing electrons to move from inner orbits to higher energy levels. This measurement is done using energy-dispersive and wavelength-detecting techniques. With this device, measurements can be taken to a depth of several micrometers/millimeters (Figueiredo et al., 2010; Liritzis & Zacharias, 2011; Sandu et al., 2011b; Oyedotun, 2018).

The principle of XRF analysis is based on the ability to identify elements by the unique energy released when an X-ray ejects an electron from the K-band of an atom, and another electron from the L-band transitions to the K-band to stabilize the atom (Çetinkaya, 2010). This non-destructive and non-invasive method allows for the in-situ, rapid, and highly accurate characterization of cultural heritage without causing damage. As a result, it has been adopted in the fields of architectural and archaeological conservation (Frahm & Doonan, 2013; Acquafredda, 2019; Leone et al., 2019; Li et al., 2020; Bersch et al., 2021; Pecchioni et al., 2021; Pehlivan, 2022a; Pehlivan, 2022b; Pehlivan, 2023; Zhang et al., 2024).

Although analyses conducted with portable XRF devices are non-invasive, contactless, non-destructive, and do not require sampling or surface preparation, making them easy to apply and offering straightforward data processing, it is essential to consider that the device can measure depths greater than 100 µm when interpreting the results (Figueiredo et al., 2010; Sandu et al., 2011b).

Another limitation of XRF analysis is surface contamination. Atmospheric pollution, particularly on façades located in urban centers, can be a common issue. Another source of contamination arises from human contact with the surface. Such pollutants may not always be visible but can appear in XRF analysis results. Therefore, unless a patina that must be preserved is present, surface cleaning is recommended prior to analysis. Since the likelihood of surface contamination is higher in the case of light elements, this factor must be considered during experimental studies. Several studies have highlighted this issue by reporting the presence of anachronistic elements (Pahlke et al., 2001; Ogburn et al., 2013; Tissot et al., 2018; Bicchieri et al., 2020). Furthermore, on surfaces exposed to moisture, salt deposits may remain after the evaporation of water, which can also interfere with XRF analysis (Di Castro Silva et al., 2025).

2.2. Application of the Method

Numerous experimental studies have employed the XRF method for gilded or gold-containing cultural heritage. Miliani et al. (2009) conducted XRF analysis on the surface paints of a group of ceramics and identified examples where gold, brass, or a combination of both were used. Figueiredo et al. (2010) used XRF analysis to perform the elemental characterization of a gilded nail and, unusually, concluded that the gold-gilded nail was made of copper rather than the more commonly used bronze. Simsek et al. (2015) applied XRF to study the gilded decorations in Early Böttger ceramics, while Gao et al. (2016) and Colomban et al. (2020) used it for the characterization of gold leaf. Pessanha et al. (2019), Barcellos Lins et al. (2020), and Orsilli et al. (2023) utilized XRF to measure the thickness of gold leaf. Hinds et al. (2014) employed XRF to detect platinum content in Roman gold coins. Schwantes and Trachet (2020) experimented with XRF analysis to distinguish whether a yellow-painted surface pigment was iron (III) oxide-based, or ochre, successfully making the identification with XRF. Fanti and Furlan (2020) applied XRF for provenance analysis of gold particles found on a shroud. Brocchieri et al. (2022b) demonstrated through XRF analysis that a group of gilded lead artifacts at the Royal Palace in Caserta were gilded with real gold. Margreiter et al. (2022) produced amalgam gilding experimentally to prove that XRF can be used as a non-destructive inspection method. Tissot et al. (2018) and Guerra and Pagès-Camagna (2019) used XRF to determine the gold content of jewelry, Steger et al. (2021) to detect the elements forming gilded metallic pigments in stained glass, Brocchieri et al. (2022a) for the characterization of gilded decorations, Marchetti et al. (2023) for elemental analysis of gold flakes, Gattia and Seccaroni (2023) for identifying gilded threads in silk and carpets, and Vadrucci et al. (2024) for the characterization of a gilded leather artifact. Povolotckaia et al. (2025) employed XRF analysis to prove that a rare technique called "mizunotype" applied on a wooden panel was created using gold.

In this study, the portable XRF device used was the Thermo Scientific Niton XL3t analyzer with a GOLDD+ detector. Its resolution is below 185 eV, with a measurement rate of 60,000 cps and a shaping time of 4 µsec. The X-ray tube operates with a silver anode at 50 kV and 200 µA. The device is capable of measuring elements from magnesium (Mg) to uranium (U) with a resolution of 5 mm. It features a self-calibration function that utilizes measurements from a standard metal.

Since the gilded decoration is located indoors, the risk of atmospheric pollution was low. Nevertheless, to prevent contamination from surface contact, a simple cleaning was performed. The surface was wiped with a lightly dampened cloth, dried, and subsequently measured by positioning the device approximately 1 mm from the decoration at a 90° angle for about 125 seconds, generating spectra for the 60-Light Range, 90-Low Range, and 120-Main Range.

Data processing was carried out using the "Standard Thermo Scientific™ Niton Data Transfer (NDT™) PC software" developed by the manufacturer and compatible with the device. The software provided the intensity of the detected elements in counts per second (cps), which were then converted into parts per million (ppm) and presented in column charts.

The data obtained from XRF analysis were evaluated within the context of the literature review on traditional gilding techniques. The absence of certain elements led to the elimination of some techniques, while the consistency of the detected element ratios with those reported in the literature helped identify the original gilding technique used in the decoration.

3. Findings

The XRF spectra obtained from the gilded ornamentation analyzed using the p-XRF device were converted into graphs in terms of keV for the spectrum and ppm for the element concentrations. Elements that could not be detected in the analysis were not included in the graph.

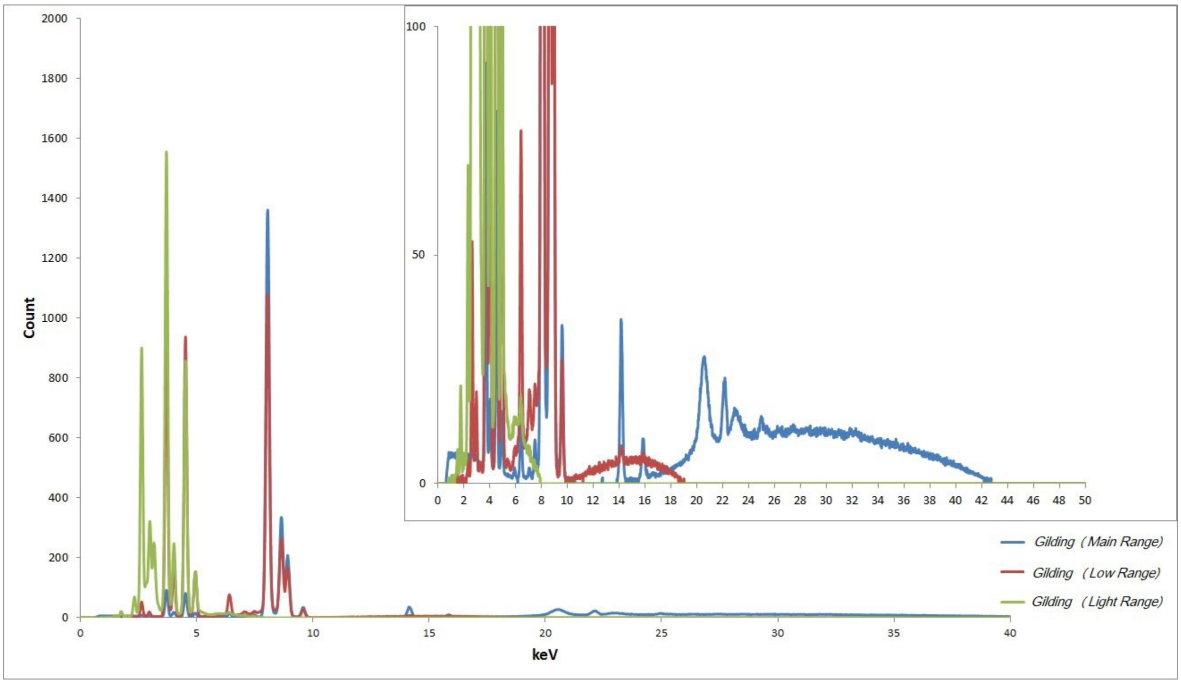

Figure 7 XRF spectrum of the gilded ornamentation

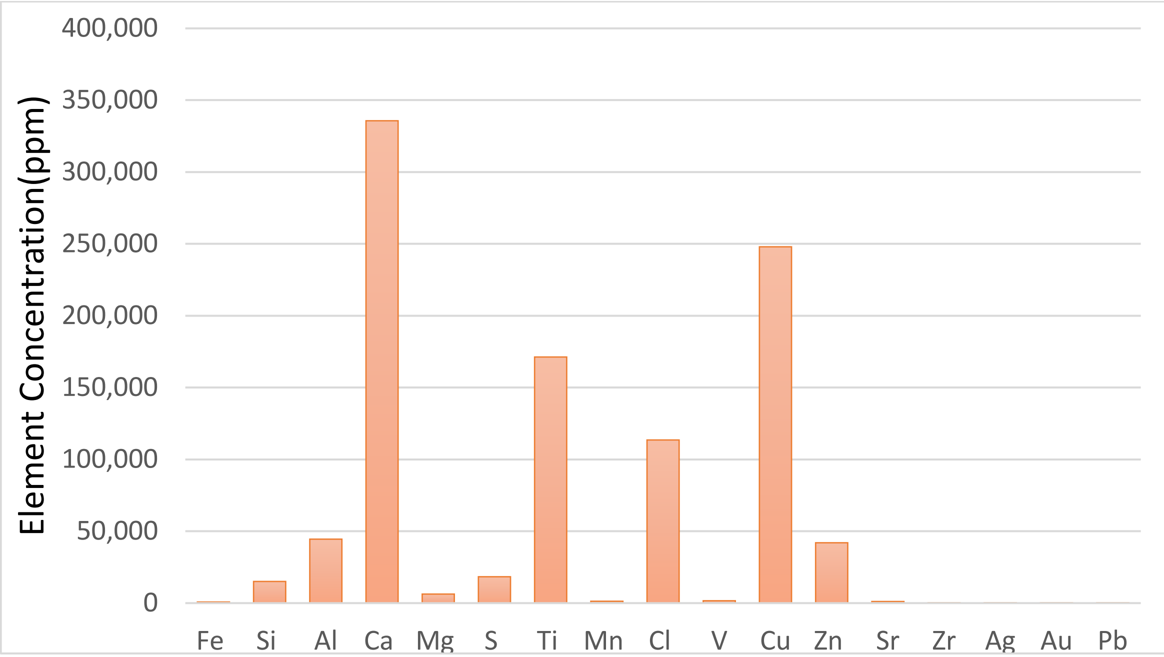

Figure 8 Graph showing the elemental concentrations in the gilded ornamentation

According to this, it is observed that the element with the highest concentration is calcium, followed by copper, titanium, chlorine, aluminum, and zinc. The analysis revealed that certain elements such as mercury, chromium, tin, cadmium, and bismuth were not present. Gold, silver, lead, zirconium, iron, strontium, vanadium, and manganese were found in negligible amounts (below 0.2%), while silicon, magnesium, and sulfur were present in concentrations below 2% (Figures 7 and 8).

4. Discussion and Conclusion

Gold is typically not found in its pure form in nature. Particularly, gold without silver indicates refined gold. Copper is not commonly used as an alloy in gold because it makes the metal harder to be forged; however, natural gold does contain a small amount of copper. Natural gold typically contains approximately 40% silver, 5% iron, and 1% copper (Figueiredo et al., 2010; Sandu, 2011b).

To determine whether the gilding is made of real gold, the presence of the aforementioned elements should be checked. In the examined artifact, gold is found at 0.0026%, silver at 0.0131%, and iron at 0.0762%.

The negligible amount of gold confirms that this ornamentation was not produced from real gold but is a gold imitation. When analyzing the graph in Figure 8, the proportions of copper and zinc—elements commonly used in imitation gilding—are noteworthy. The ratios used to achieve a gold-like color are known to be approximately 1/5 to 1/6 (14/86) (Britannica, 1998; Craddock et al., 2004; Thornton, 2007; Duran et al., 2008; Steger et al., 2021; Parma et al., 2023). The zinc/copper ratio in the examined gilded ornamentation is found to be 1/6 (14/86), consistent with the literature (Figure 9).

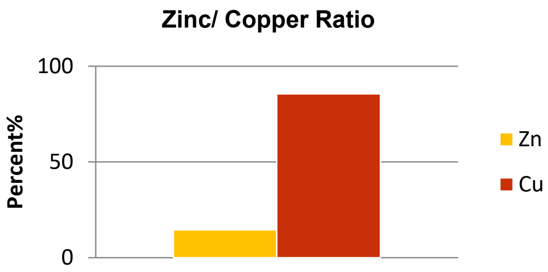

Figure 9 Graph showing the zinc/copper ratio in the gilded ornamentation

In addition to copper and zinc, other techniques used for gilding imitation were also evaluated. For the powder tin sulfide application, the presence of tin, mercury, and sulfur is required; however, the absence of tin and mercury, along with the trace amount of sulfur, eliminates this technique. The use of tin and silver leaf as another gilding imitation technique is not feasible due to the absence or trace amounts of these elements.

Some yellow-orange pigments used in gilding production include: iron oxides (madder colors), minium (Pb3O4), chrome yellow (Paris Yellow—PbCrO4), chrome orange (PbCrO4•PbO), vermilion (α-HgS), and Pb-Sn yellow (gialolino) (Cavallo & Verda, 2008; Duran et al., 2008; Rampazzi et al., 2008; Sansonetti et al., 2010; Perez-Rodriguez et al., 2013; Kekeç, 2022). Another pigment used to produce metallic yellow is orpiment (As2S3) (Jackson & Jackson, 1976). Another pigment used for gold imitation is zinc potassium chromate (Śwituszak et al., 2023). Nickel antimonate, cadmium pigments, bismuth vanadate, and bismuth molybdate are also other yellow pigments (Tunçgenç, 2004).

Elemental analysis shows the absence of the aforementioned arsenic, chromium, potassium, mercury, and tin; lead and iron are found in negligible amounts. Therefore, the presence of yellow-orange pigments used in gilding production cannot be confirmed. Additionally, since cadmium, nickel, antimony, and bismuth are absent, and vanadium is present only in trace amounts, the presence of other yellow pigments cannot be discussed either.

The density of copper and zinc in the elemental analysis and their conformity to the ratios reported in the literature confirm the use of a brass alloy for gilding imitation. It is important to focus on whether brass leaf or brass powder paint was used. It is known that brass leaf surfaces are burnished. However, in the ornamentation, there is no evidence of burnishing; instead, there are traces of a liquid paint consistency (Figure 6). Therefore, it can be concluded that the ornamentation consists of a brass powder-based gilding imitation paint.

In gilding imitation paints, in addition to copper and zinc, elements such as tin and nickel may occasionally be present in small amounts (Steger et al., 2021); however, none of these elements were found in the examined artifact.

When evaluating the findings, it is necessary to address certain characteristics and limitations of the XRF analysis. As mentioned above, XRF can measure depths greater than 100 µm (Figueiredo et al., 2010; Sandu et al., 2011b). This feature explains the high concentration of calcium observed in Figures 7 and 8. The high concentration of calcium is due to the traditional lime mortar layer beneath the gilding. This is because the XRF device can analyze down to a few micrometers below the gilding.

To reduce the risk of contamination, surface cleaning was performed prior to analysis. Moreover, most of the elements detected in this analysis are heavy elements, which are less susceptible to surface contamination (Pahlke et al., 2001; Ogburn et al., 2013; Tissot et al., 2018; Bicchieri et al., 2020). The concentration of aluminum and silicon elements is likely due to the presence of aluminosilicate within the mortar. The concentration of titanium is probably derived from titanium dioxide pigment, which is commonly used in white paint applied over the lime mortar and known for its high opacity (Middlemas et al., 2013; Karlsson et al., 2018). The presence of chlorine indicates the accumulation of salts on the surface (Di Castro Silva et al., 2025).

Portable XRF analysis (p-XRF) is effective in detecting a wide range of metals and non-metals; however, due to its low sensitivity for elements smaller than magnesium, it has limited ability to detect organic pigments containing C, H, and N. The pigments used for imitation of golden yellow are mentioned above. Since the pigments commonly used to imitate gold do not contain these elements, the study was not adversely affected by this limitation of the XRF technique.

Based on the analysis, it has been done that a lime mortar layer and paint be applied to the wall surface first, followed by brass powder paint for gilding imitation. A restoration approach in accordance with this technique is advised.

This study presents a non-destructive, contactless, and non-sampling method for understanding the content and production technique of gilded ornamentation in a cultural heritage. It is suggested that portable XRF devices and the units using them (such as laboratories, centers, university-affiliated institutions, and advanced technology offices) be more widely disseminated. Furthermore, it is recommended that the Cultural Heritage Preservation Regional Board Directorates make the use of such methods mandatory through a policy decision. This would enable restorations to be carried out in a manner that is scientifically accurate and true to the original, beyond the intuitions and personal knowledge of the restorers.

Due to the limitations of the study, the research focused on the gilded decoration of a traditional house in Sivas, serving as an example of the applicability of a new technique, namely non-destructive XRF analysis, to the field of conservation and restoration science.

This study, constrained by time, working conditions, and the format of the article, addressed a single case study. For future research, it is recommended to expand the sample size by analyzing a greater number of gilded decorations and conducting comparative analyses. As such studies increase, documenting the elemental composition of gilded decorations will contribute to building a significant database for understanding the production techniques of the period and the distribution networks of these techniques.

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CRediT Authorship Contribution Statement

Gamze Fahriye Pehlivan: All prepared by Pehlivan. Investigation, writing, review & editing, methodology, data curation, conceptualization etc.

Declaration of Competing Interest

The author declare that she has no known competing financial interests or personal relationships about this paper.

Acknowledgements

I would like to thank Assoc. Prof. Dr. Ali ÖZER, Sivas Archaeological Museum Director Ali ALKAN, and Assoc. Prof. Dr. Erdener PEHLİVAN for their support throughout this study.

Data Availability

Data will be made available on request.

Ethics Committee Approval

An ethics committee decision is not required.

Resume

Gamze Fahriye PEHLIVAN graduated from the Department of Architecture of Trakya University. She obtained her master's degree from the same university. She took some master lessons in the Restoration Department of Yıldız Technical University. She specializes in preserving cultural heritage. She has been an Associate Professor of the Architecture Department of Sivas Cumhuriyet University.