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The coffin-reliquary of the holy Serbian king Stefan of Dečani (fourteenth century): wood, pigments and metal surfaces

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Abstract

The coffin-reliquary for the relics of the holy Serbian king Stefan Uroš III of Dečani has been made around 1343 as a rectangular chest with a gable cover. The present study aimed to identify the wood this coffin-reliquary was made, as well as the pigments and metals found on its surface. The combination of anatomical traits (diffuse-porosity, distinct helical thickenings in vessels, simple perforation plates, 3- to 4-seriate noded rays and diffuse-in-aggregates axial parenchyma) showed that the wood belongs to linden, i.e., to the botanical genus *Tilia* L. (Malvaceae). The linden is one of the sacred trees in Serbian culture, and its wood could also be used due to its ease for joinery. X-ray fluorescence spectroscopy (XRF analyzer) was used for in situ determination of the material chemistry of the pigments, as well as the metals on the wooden surfaces of the coffin. Their elemental composition showed that wooden coffin-reliquary was painted with vermilion, malachite or copper resinate, orpiment, and lead white, while metal surfaces were shown to be gold and silver. Unlike a commonly used palette of earthy pigments, these coloring matters belong to precious noble pigments.

Keywords Conservation, Cultural heritage, Historical wood, Wooden artifacts

Introduction

Human bond to wood over thousands of years is embedded in wooden cultural heritage (WCH) representing human life and values [1]. Any wooden artifact that provides us data regarding human life and culture, and that is considered worthy of preservation for the future can be defined as wooden cultural heritage [2]. Funeral objects, particularly coffins, represent a valuable source of information about ceremonies, applied art, material treatment, and handicraft traditions.

The choice of wood used in works of applied art was based on their availability, its symbolism in the culture, and their suitability for particular tasks (e.g., furniture is made from woods carefully selected for their appearance and strength, durable woods for coffins, soft wood for carving, etc.). This specifically documented the folklorist Josef Blau [3] who determined the woods of 27 plant species in Bohemian household, emphasizing that all species were chosen according to their specific wood properties. Thus, the traditional uses of wood and the skills in selection of woody species could provide us knowledge which might be useful today [4]. While such knowledge

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is mostly lost nowadays, it can be partly rediscovered through identification of woods in the collections of museums, which are important sites for the preservation of traditional experience in the form of material goods. The investigation of wooden artifacts helps to understand the wood uses in the past, providing information on their cultural significance and also on the historical period during which they were probably made [5]. The exact identification of wood is essential for assessing the state of conservation of the artifacts, to support or suggest the most appropriate methods of intervention, to know the technological properties of wood and the natural durability and to collect data on the working choices and methods of the past craftsmen [5].

In medieval Serbia, the holy relics of saint Serbian rulers, church dignitaries and distinguished anchorites played key role in strengthening of the Orthodox faith and the state authority considered as having Divine origin [6]. The relics of some Serbian monarchs, such as venerable Simon's (king Stefan the First-Crowned) relics at the Studenica Monastery, Saint king Milutin's relics in Saint Kyriaki church at Sofia (Bulgaria), Saint king Stefan of Dečani's relics at the Dečani Monastery, Prince Lazar's relics at the Ravanica Monastery, etc., have been perfectly preserved to the present [6]. Some of the holy relics of the Serbian saints were laid in lavishly decorated coffins and given the place of honor in front of the iconostasis [6]. The coffin-reliquary of Saint Stefan of Dečani was undoubtedly an object of the highest cult rank. The coffin-reliquary, which was believed to possess the same miraculous powers as the relics themselves, convincingly embodied the idea of the saint's presence [6]. For centuries, believers showed great respect both to the relics and to the coffin-reliquary, praying at them and kissing both of them. There was also the practice of passing under the coffin, which originally stood on high wooden legs [6].

The coffin-reliquary for the relics of the holy Serbian king Stefan Uroš III of Dečani (r. 1322–1331) has been made around 1343 as a rectangular chest with a gable cover. It originally stood at the church of Christ Pantokrator in Dečani, in front of the templon. The placement of the coffin-reliquary there had influenced the program of the surrounding frescoes, as well as the development of the Dečani Monastery templon and its symbolic meaning [7, 8]. In the nineteenth century (1848–1849), the relics were transferred to a newly made wooden reliquary-coffin [9]. The original coffin made in fourteenth century has been relocated to the treasury of the Dečani Monastery first, and from 2013 it is displayed at the permanent exhibition of the Museum of the Serbian Orthodox Church in Belgrade [10]. The relics of the holy king Stefan of Dečani left at the Dečani Monastery, inside of the marble coffin in front of the templon, on south side.

The oldest coffin-reliquary of Saint Stefan of Dečani is a unique piece of the Serbian medieval art and Byzantine art in general, being one of the rare applied art objects made of wood in fourteenth century, and preserved until today. The dimensions of the coffin-reliquary are 197 × 60 × 43.5 cm (the chest of the coffin-reliquary is 197 cm long, 60 cm wide and 43.5 cm high, and the lid is 196 cm long, 61.5 cm wide and 20 cm high) (Fig. 1a). The lid, the front and the right side of the coffin-reliquary are decorated with the woodcarving, gilding and various colors, dominated by red. Its carved geometric, floral and zoomorphic ornaments finished by painting and gilding evoke the heavenly abode the saint dwells in. The most striking features are the rosettes with intricate interlaces (Fig. 1b, f, g) and animal representations: two panthers and a lion and lioness in the corners of the central panel (Fig. 1c) and a panther in the center of the panel on the right side (Fig. 1d). The square panel on the lower right side of the chest has a round medallion with a hexagram, i.e., the Star of David (Fig. 1e). Gilded elements include the six larger prominent ornaments on the lid, which have the shape of a single and multi-part, circular foliated vine with a red-green flowers (Fig. 1g), and an interlace in the triangular panel on the left and right side of the lid (Fig. 1f).

The whole coffin-reliquary was colored with red, green, blue, and yellow paint applied after the surface was primed with gypsum, and light accents were added in white paint, mostly on the flower leaves and the bodies of the panthers and lioness. The carved elements were made directly on wood, except for the three large panels on the frontal side of the chest, which were produced separately, using the openwork technique and then inserted into the premade beds [11]. The inside of the coffin-reliquary is undecorated [11–13].

Based on available documentation from the Republic Institute for the Protection of Cultural Monuments of Serbia, the first conservation interventions on the coffin-reliquary of Saint Stefan of Dečani were carried out in the 1960s. The wood was badly damaged by insects and the carved and painted parts of the coffin were covered with deposits of various impurities. After removal of these deposits by a combination of mechanical and chemical methods, disinsection and consolidation of damaged wood surfaces have been carried out. The holes, that is, the exit openings of insects were filled with pure beeswax that has been softened with a suitable solvent. Twenty years later, additional conservation and restoration interventions were carried out, contributing to a better understanding of the coffin-reliquary's artistic and sacred values [14].

Wood identification is the first step of studying and conserving historic wooden artifacts. To date, there is no

Fig. 1 Coffin-reliquary of the holy Serbian king Stefan of Dečani (**a**) and details of floral and zoomorphic ornaments (**b**-**g**)

research conducted in Serbia regarding identification of wood species for wooden artifacts, based on anatomical characters. Recently, our group has started to identify wood in cultural heritage objects in cooperation with the Institute for the Protection of Cultural Monuments of Serbia and the Museum of the Serbian Orthodox Church in Belgrade. Thus, the objectives of the present work was to identify wood species from which the existing coffin-reliquary of the holy Serbian king Stefan Uroš III of Dečani is made of and possible to find out why such certain wood species is used. Another goal was to identify pigments and metals on the surface of coffin and ornaments. In order to determine concerning materials used for painting, gilding and artistically adorned fetters X-ray fluorescent spectroscopy (XRF) as suitable non-destructive analytical technique has been chosen. The knowledge of applied materials and their properties will be useful in planned future conservation and restoration treatment.

Material and methods

Wood anatomy

In this study, wood identification was performed on three samples (one from the coffin-reliquary (Fig. 2b) and two from the lid (Fig. 2c)) obtained from coffin-reliquary of the holy Serbian king Stefan Uroš III of Dečani which is kept in the Museum of the Serbian Orthodox

Fig. 2 Analyzed points by XRF spectroscopy on coffin-reliquary (**a**), sampling from the coffin-reliquary (1 sample) (**b**), and from the lid (2 samples) (**c**)

Church, Belgrade, Serbia (Fig. 1). Samples (ca. 0.5 cm^3) were carefully taken using Olfa cutter with Olfa UltraMax® LBB-10 blade from cracks and naturally occurring hollowing of the coffin-reliquary with the consultation of the curators and conservators, without harming the surface and appearance of the object. Temporary sections (cross, radial, tangential, approximately 15–30 µm thick) from all three samples were made by hand using a sharp microtome Leica knife. Observations of the obtained microslides were performed on a light microscope Leica DM2000 equipped with a digital camera Leica DFC320 and a computer with the imaging software Leica IM 1000. The identification of wood species was carried out using the InsideWood database [15] and relevant literature [16, 17].

X-ray fluorescence spectroscopy (XRF)

Six different colored spots and two metal surfaces were analyzed. The analyzed positions are marked on Fig. 2a. Analyses were done in situ using handheld Thermo Scientific Niton XL3t Gold X-ray fluorescence (XRF) analyzer, with a 50 kV X-ray tube, large area drift detector and automatic voltage and current optimization based on sample and range of elements. In order to isolate small areas of interest and to provide information about chemical composition of artist`s palette, the CCD camera and sample imaging system with integrated 3 mm spot collimation was used. The spots of interest were analyzed in All Geo calibration mode plus light element analysis (Mg, Al, Si, P, S) without helium or vacuum purging. Two metal points were analyzed in general metal mode. Filters for main, high, low and light elements were all used in total time of 90 s per sample. The Niton Data Transfer software suite was used to process results.

Results

Anatomical structure and identification of wood samples from the coffin-reliquary

Our investigation showed that the wood of all three samples was anatomically identical. Codes of the anatomical traits [16] used for the InsideWood [15] search are given in notation brackets.

Anatomical description. Growth ring boundaries distinct, marked by 2 to 3 rows of thick-walled, radially flattened cells and distinctly noded (flaring) rays (Fig. 3a). Wood diffuse-porous (5p) with a tendency to semi-ring-porosity (Fig. 3a). Vessels solitary and in radial multiples and small clusters up to 4 (11p) (Fig. 3a), small to medium (27–74 µm in diameter). Solitary vessel outline is angular (12p) (Fig. 3b). Perforation plates simple (13p). Intervessel pits alternate (22p) (Fig. 3c–e) medium to large (8.8–14.1 (mean 11.4 ± 1.3 µm) in horizontal diameter (26p)] and 6.9–10.2 µm (mean 8.2 ± 1.3 µm) in vertical diameter. Vessel-ray pits are bordered, similar to intervessel pits is shape (30p)], but somewhat smaller (horizontal diameter 3.0–7.2 µm (mean 5.0 ± 0.9 µm) and vertical diameter 2.4–6.4 (mean 3.9 ± 0.8 µm)) (Fig. 3f). Vessel element about 220–460 µm in length. Conspicuous helical thickenings common (36p, 37p) (Fig. 3e, f). Fibers libriform, thin- to thick-walled (69p), nonseptate (66p), about 240–1180 µm in length. Apotracheal axial parenchyma diffuse-in-aggregates (77p) (Fig. 3b), in strands of 3–6 (92p, 93p). Rays uni-, bi- to 4-seriate (Fig. 3g, h), composed of procumbent cells (Fig. 3f), occasionally also with a row of square marginal cells (106p). Storied arrangement of axial parenchyma strands (120p) (Fig. 3i). Ray height very variable.

The InsideWood [16] search (5p, 11p, 12p, 13p, 22p, 26p, 30p, 36p, 37p, 69p, 66p, 77p, 92p, 93p, 106p) returns three European species of *Tilia* (*Tilia cordata* Mill., *Tilia platyphyllos* Scop. and *Tilia × europaea* L.), *Olearia paniculata* (Asteraceae) and two species of *Prunus* (*Prunus phaeosticta* (Hance) Maxim. and *Prunus spinulosa* Siebold & Zucc., Rosaceae). Unlike the samples under study, however, most of these species (except *Tilia*) share the vessel arrangement in diagonal, radial, tangential or dendritic pattern. Also, *Olearia paniculata* (Asteraceae) from New Zealand does not have distinct growth rings boundaries, possessing septate fibers, paratracheal axial parenchyma as well as storied rays and vessel elements, i.e., the characters which were not found in our wood samples. *Prunus phaeosticta* (Hance) Maxim., and *Prunus spinulosa* Siebold & Zucc. (Rosaceae) from eastern Asia differs from the studied woods by longer fibers (900–1600 µm in length), extremely rare or scanty paratracheal axial parenchyma as well as by the rays of two distinct sizes. Therefore, the wood samples from the coffin-reliquary show greatest similarity to the plant genus *Tilia* (Malvaceae), i.e., to linden. The only distinctive feature of our samples lacking in the InsideWood record for the European species of *Tilia* is the occurrence of storied axial parenchyma. This trait has been reported in the wood of *Tilia* by other authors [18]. Thus, our data strongly suggest that the coffin-reliquary of the king Stefan of Dečani made of linden wood belonging to one of European species of *Tilia* (*T. cordata*, *T. platyphyllos*, or *T. × europaea*). The anatomical characteristics of the wood, however, do not allow us to determine with certainty to which of these three species the sample belongs.

Elemental composition of colored surfaces and metallic parts of the coffin-reliquary

On the base of present elements (Tables 1, 2), wooden coffin-reliquary was painted with vermilion, orpiment, azurite, lead white, and copper-based green pigment (malachite, verdigris or copper resinate as these pigments are not possible to distinguish by XRF analytical technique). Preparatory layer is gypsum based, due to the high presence of calcium and sulphur in all analyzed colored spots. Shiny yellow gilded decorations on carvings were performed with gold leaves while nailed metal pieces and traces of former ornamental metal band on the edges of coffin were derived from silver.

Dominant red color comes from pigment vermilion, compound of mercury and sulphur (HgS). Both constitutive elements are present in significant amounts on red analyzed surfaces. Floral motifs are intermittently decorated with white details. Lead is main element in XRF spectra on these points indicating the use of lead white pigment ($2PbCO_3 \cdot Pb(OH)_2$). The presence of calcium was detected in significantly lower concentration compared to lead and likely originates from the composition of preparatory layer rather than the lime white pigment. The elements zinc and titanium are not present in the composition of the analyzed white surfaces, thereby excluding the possible presence of zinc white and titanium white due to restoration intervention. On brightly yellow surfaces, arsenic and sulphur are present in high concentrations leading to the conclusion that yellow pigment is arsenic (III) sulfide (As_2S_3). Copper is green color provider given that it has been detected on dark green zoomorphic motifs on the front side of the coffin. It could be: malachite ($CuCO_3 \cdot Cu(OH)_2$), verdigris ($Cu(CH_3COO)_2$) or copper resinate.

Light blue layers are performed with azurite ($2CuCO_3 \cdot Cu(OH)_2$). Besides copper as the dominant element in spectra of the blue spots, small amounts of cobalt are present, too. Arsenic, copper and sulphur are present

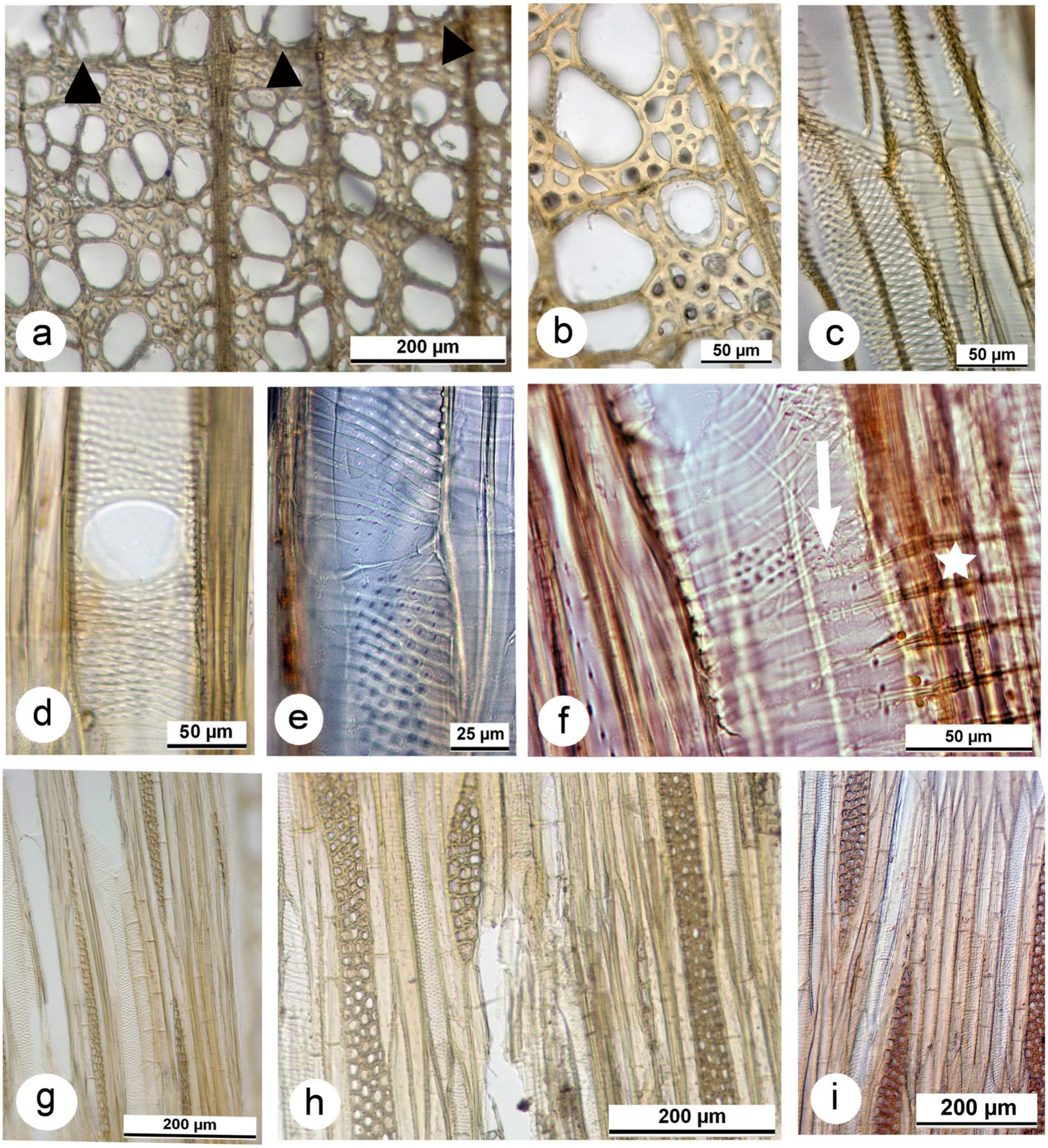

Fig. 3 Light micrographs showing anatomical characters of the linden wood: distinct growth ring boundary (arrowhead), diffuse-porosity, noded rays and small clusters of vessels (TS) (**a**), diffuse-in-aggregates axial parenchyma (TS) (**b**), conspicuous helical thickenings on vessel walls (TLS) (**c**), simple perforation plates (TLS) (**d**), alternate intervessel pits (TLS) (**e**), procumbent ray cells (asterisk) and bordered vessel-ray pits (arrow) (RLS) (**f**), uni- and biseriate rays (TLS) (**g**), uni- and 3–4-seriate rays (TLS) (**h**), storied arrangement of axial parenchyma strands (TLS) (**i**). *TS* transverse section, *RLS* radial longitudinal section, *TLS* tangential longitudinal section

in light green colored layers. Pigments that can give a light green tone may contain copper in their composition, such as verdigris, malachite, and copper resinate. However, the high concentration of arsenic and sulfur indicates the presence of the yellow pigment orpiment. Based on the composition, it appears that the painter in this case chose to obtain desired green color by mixing yellow and blue rather than using the usual painting

Table 1 Elemental composition of analyzed colored surfaces

Sample	Color	Elemental composition (by XRF)	Pigment
1	Dark green	Cu, Pb, Ca, Fe, Ti, Zn, Mn, Al, Si, S, Cl	Malachite, verdigris or copper resinate
2	Red	Hg, S, Pb, Ca, Fe, Cu, K, Al, Si, P, Cl	Vermilion
3	Light green	As, S, Cu, Ca, Fe, Mg, K, Al, Si, Cl	Mixture of orpiment and azurite
4	Blue	Cu, Ca, Fe, Pb, Ti, Co, Al, K, Si, S, Cl	Azurite
5	Yellow	As, S, Ca, Fe, Mg, K, Al, Si, P, Cl	Orpiment
8	White	Pb, Hg, S, As, Ca, Cu, Fe, K, Al, Si, P, Cl	Lead white

Table 2 Elemental composition of analyzed metal surfaces

Sample	Metal surfaces	Elemental composition (by XRF)	Metal
6	Gilded surfaces	Au, Fe, Si, Al, Cu, Pb, Zn	Gold
7	Traces of silver band	Ag, Cu, Si, Fe, Au, Zn, Pb,	Silver

technique of tonal modulation with white and green. It seems that detected copper likely originates from the blue azurite, which was used to decorate the surrounding blue surfaces, rather than green pigments that contain copper in their composition.

Very high concentration of gold on the analyzed interlaces of the coffin woodcarving strongly suggests that the gilding ornament are performed with gold leaves. The former metal ornamental band remained only as small parts around the nails, was made of silver, as its very high content of this metal.

Discussion

The linden tree has rich and diverse symbolism in the cultures of European folks. The Serbs and Slavs in general considered it as a holy tree [19]. Linden wood was commonly used by them for the making of sculptures and ornaments in early medieval churches in Europe [20]. In the Slavic Christian world there is a tradition that altar screens, statues of the Virgin Mary, Christ and Saints are mostly carved from linden wood (*lignum sacrum*), that is considered holy [21]. As this wood is soft and easy to work with, it is also a wood of choice for painting the icons on it [22]. Wooden support of the statue of Saint Joseph (workshop of Ignaz Günther, eighteenth century) was identified as linden wood [23].

In Slav burial customs, the linden was a coffin tree, probably due to its soft logs were easy to carve [24]. Also, it was documented that most mummy portraits (funerary artifact), which were popular in the first through third centuries AD in Egypt, were made of linden wood [25], which was imported in Egypt. In addition, Dabralet et al. [26] documented that internal child coffin (nineteenth century) from the Southern Crypt of the Holy Trinity Church in Radzyń Podlaski was made of linden wood. In Polish lands, it is believed that a linden coffin protected the dead from disturbances during eternal rest [27].

The selection of individual wood species for specific purposes in specific geographic regions is likely based on their local availability and the esthetical and durability properties [4]. Thus, the results of our study support the local origin of the coffin-reliquary and the material used. Therefore, we can assume that linden wood was used because it is easy to process and because it is considered as one of the sacred trees in Serbian culture.

Four species of *Tilia* occur in Europe [28]. The most widespread, *T. cordata* Miller, has its core region in Central and Eastern Europe, its northern latitudinal boundary in southern Fennoscandia, its altitudinal limit at 1500 m in the Central Alps [29] and disjunct populations in Crimea and the Caucasus. *T. platyphyllos* Scopoli, has a smaller range: slightly farther spread southward and in its northern boundary reaching southern Sweden, and spread only in the westernmost parts of the East European Plain [28]. This taxon hybridizes with the *T. cordata* in *T.* × *vulgaris* Hayne (= *T.* × *europaea* L. p.p.). *T. tomentosa* Moench is distributed in the Middle East, i.e., northwestern Anatolia (Marmara Sea and Black Sea; [30]) and SE Anatolia, but its main range extends in SE Europe: Greece, Albania, Macedonia, Serbia, Montenegro, Bulgaria, Romania up to southern Hungary [29]. *T. dasystyla* Steven occurs in southern Crimea, Black Sea coast of Anatolia; Caucasus, and Alborz Mountains [31]. Abovementioned *Tilia* species, except *T. dasystyla*, occur on Balkans.

According to ethnobotanical data [32], the Serbians can distinguish between three species of *Tilia* using different vernacular Serbian names for (sitnolisna lipa for *T. cordata*, krupnolisna lipa for *T. platyphyllos* and srebrna lipa for *T. tomentosa*). Although, all three species are used in the same way to treat respiratory complaints, the interviewers mentioned *T. cordata* more frequently than other two species [32]. However, we did not find any evidence that the woods of these three *Tilia* species were distinguished either by Serbian wood men, or by the common people. It is highly unlikely that these woods were distinguished in the medieval Serbia too. Thus, a strict identification of the *Tilia* species is not crucial for attribution and cultural exploration of the studied artifact.

Red color is predominantly represented on coffin colored layer and majority of colored decorations were made using it. Vermilion, pigment used to paint red surfaces, has been highly valued since ancient times. Its cost was about ten times higher than that of calcined ochre, another red pigment [33]. Instead of commonly used ochre, the artist chose to paint yellow parts of coffin with arsenic (III) sulfide (As_2S_3) known as the pigment orpiment also known under the name auripigmentum after its resemblance to the gold [33]. The lead white was used by the painter for meticulously decorated accents on flower petals as well as for achieving of desired tones of other applied colors. Painters skillfully combined complementary red and dark green colors on zoomorphic motifs. Unfortunately, we were not able to determine the dark green pigment with confidence. The limitations of the XRF technique did not allow to distinguish between different green copper-based pigments.

The predominant practice among medieval painters was to use certain pigments directly rather than mixing them [34]. We found, however, that the artist applied an unconventional solution by mixing yellow orpiment and blue azurite to get the light green tone. Blue colored surfaces are performed with pigment azurite and small amount of cobalt. Blue cobalt pigments as cerulean blue (cobalt stannate ($CoSnO_3$)) and smalt (potassium glass containing cobalt) are much later introduced in usage than the time period of making coffin (compendium). As the coffin was restored in twentieth century, traces of cobalt probably originate from retouches of adjacent fields. Azurite is also another one which does not belong on the symbolic level to the reality of earthly world. It is associated with sky and sea.

The palette of pigments found on the coffin-reliquary of the king Stefan of Dečani shows a certain resemblance to that of highly decorated and wood-carved door located in the Church of Dionysiou monastery from Mount Athos. This door, dated also in fourteenth century, is painted with orpiment, lead white, vermilion, red lead, red ochre, carbon black and colorant of indigoid family [35]. Precious orpiment and vermilion are present on both objects with obvious attention of the artists to accentuate their nobility. As the coffin-reliquary has more sacral character than door of the church due to the idea of holiness, painter chose to use blue azurite and coppery based green pigment instead of common red ochre and carbon black. The painter choice it is indicative that used colors does not belong to usual, well-known palette of earth pigments, in the other words to those like ochre, sienna, umbra or green earth which consist mainly from iron oxides and are widely spread in nature. Understanding purpose of the coffin as the sacral object, the artist made a clear distinction between earthly and heavenly realm symbolically using uncommon precious, noble pigments and expansive gold and silver to convey this differentiation.

Conclusion

Wood identification, as well as material chemistry of the pigments and metals were performed on the reliquary-coffin of Saint Stefan of Dečani (fourteenth century) which represents a unique piece of the Serbian medieval art and Byzantine art in general. The combination of anatomical traits revealed that the wood belongs to linden (*Tilia*, Malvaceae). The linden is one of the sacred trees in Serbian culture. In addition, linden wood could also be used due to its ease for joinery. X-ray fluorescence spectroscopy (XRF analyzer) showed that wooden coffin-reliquary was painted with vermilion, malachite or copper resinate, orpiment, and lead white, while metal surfaces were shown to be gold and silver. Unlike a commonly used palette of earthy pigments, these coloring matters belong to precious noble pigments.

Abbreviations

WCH Wooden cultural heritage
XRF X-ray fluorescent spectroscopy

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Author contributions

MG: methodology, conceptualization, wood identification, writing—original draft preparation, results explanations; AO: wood identification, results explanations, writing—original draft preparation, final reading; DR: methodology, wood identification, results explanations, writing—original draft preparation; MM, MK: sampling, conceptualization, validation, writing—original draft preparation, results explanations; AJ: methodology, sampling, conceptualization, validation, writing—original draft preparation, results explanations; PJ: sampling, conceptualization, wood identification, results explanations, final reading. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Declarations

Competing interests

The authors declare that they do not have any competing interests.

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References

1. Kim Y, Singh AP (2016) Wood as cultural heritage material and its deterioration by biotic and abiotic agents. Secondary xylem biology. 233–257

2. Rowell RM, Barbour RJ (eds) (1990) Archaeological wood: properties, chemistry and preservation. American Chemical Society, Washington, DC
3. Blau J (1917) Bohmerwalder Hausindustrie und Volkskunst. Band 1: Wald- und Holzarbeit. (Beitrage zur deutsch-bohmischen Volkskunde). Calve, Prag
4. Klein A, Bockhorn O, Mayer K, Grabner M (2016) Central European wood species: characterization using old knowledge. J Wood Sci 62:194–202
5. Lo Monaco A, Balletti F, Pelosi C (2018) Wood in cultural heritage. properties and conservation of historical wooden artefacts. Eur J Sci Theol 14:161–171
6. Popović D (2018) The Treasury of salvation. The cult of relics and Serbian saints in Medieval Serbia. Belgrade: Institute for Balkan studies of the Serbian academy of science and arts. Novi sad: Matica srpska
7. Todić B (2012) Ikonostas u Dečanima—prvobitni slikani program i njegove poznije izmene. Zograf 36:115–129 (**in Serbian**)
8. Rakićević T, Debljović Ristić N (2022) Medieval templon with inseparable objects of prostration. A case of Saints Joachim and Anna church in the Studenica Monastery. Zograf 46:73–98
9. Šakota M (1984) Dečanska riznica. Zajedničko izdanje: Prosveta—Beograd, Republički zavod za zaštitu sppomenika culture—Beograd i Jedinstvo—Priština. Beograd (**in Serbian**)
10. Matić M, Kasalica V, Jović M, Cincar Kostić B, Stokanović N (2022) Museum of the Serbian Orthodox Church. Belgrade
11. Matić M (2023) Two masterpieces of Serbian 14th century woodcarving at the Dečani Monastery: coffin-reliquary for the relics of the Holy Serbian king Stefan of Dečani and the wooden throne. In: Above the curve: Byzantine and Post-byzantine woodwork in Mediterranean and Balkan perspective, 11th–16th century, Thessaloniki (in print)
12. Popović D (2007) Shrine of King Stefan Uroš III Dečanski. In: Ewans HC (ed), Byzantium: faith and power (1261–1557), cat. no. 59, New York New Haven, NJ: Metropolitan museum of art, NY Yale University Press, New York, pp 114–115
13. Matić M (2017) The Coffin-Reliquary (Kivot) of the remains of the Holy King Stefan Dečanski, VI.27. In: Otašević D, Marković M, Vojvodić D (eds) Serbian artistic heritage in Kosovo and Metohija: identity, significance, vulnerability. Second Revised Edition, Serbian Academy of Sciences and Arts, Belgrade, p 414
14. Pantić J (2018) Rad na zaštiti dela iz oblasti slikarstva u Srbiji, in: Milorad Medić - život i delo, Društvo konzervatora Srbije, Beograd, p. 58. (**in Serbian**)
15. InsideWood (2004) Published on the Internet. http://insidewood.lib.ncsu.edu/search
16. Wheeler EA, Baas P, Gasson PE (1989) IAWA list of microscopic features for hardwood identification. IAWA J 10:219–332
17. Ruffinatto F, Negro F, Crivellaro A (2023) The macroscopic structure of wood. Forests 14:644
18. Richter HG, Dallwitz MJ (2000) Commercial timbers: descriptions, illustrations, identification, and information retrieval. http://biodiversity.uno.edu/delta/
19. Čajkanović V (1994) Rečnik srpskih narodnih verovanja o biljkama. Srpska književna zadruga: BIGZ. Prosveta, Partenon (**in Serbian**)
20. Blindheim M (1993) Utforskning av bemalt romansk skulptur. In: Berg A, Elster E, Bergendahl Hohler E, Lidén HE, Storsletten O, Tschudi-Madsen S (eds) Kirkearkeologi og kirkekunst. Bergen, pp 20–36
21. Barnet P, Brandt M, Lutz G (eds) (2013) Medieval treasures from Hildesheim. Metropolitan Museum of Art, New York
22. Ţenche-Constantinescu AM, Varan C, Borlea F, Madoşa E, Szekely G (2015) The symbolism of the linden tree. J Hortic Sci Biotech 19:237–242
23. Pelosi C, Calienno L, Fodaro D, Borrelli E, Rubino AR, Sforzini L, Monaco AL (2016) An integrated approach to the conservation of a wooden sculpture representing Saint Joseph by the workshop of Ignaz Günther (1727–1775): analysis, laser cleaning and 3D documentation. J Cult Herit 17:114–122
24. Harmata K, Madeja J, Zemanek A, Zemanek B (2009) Selected indigenous trees and shrubs in Polish botanical literature, customs and art (*Juniperus communis*, *Salix*, *Betula verrucosa*, *Populus tremula*, *Pinus sylvestris*, *Quercus*, *Tilia*, *Picea excelsa*, *Abies alba*), Plants and culture: seeds of the cultural heritage of Europe: 195–205
25. Cartwright CR (2020) Understanding wood choices for ancient panel painting and mummy portraits in the APPEAR project through scanning electron microscopy. In: Svoboda M, Cartwright CR (eds) Mummy portraits of Roman Egypt: emerging research from the APPEAR project. J Paul Getty Museum, Los Angeles Getty Publications, Los Angeles, pp 16–23
26. Dabralet I, Michalik J, Grupa M, Gałka B (2022) A double child coffin from the southern crypt of the Holy Trinity Church in Radzyń Podlaski (19th century). Ana Arch Resso. https://doi.org/10.15584/anarres.2022.17.8
27. Maciej R, Szustecka E, Buchowski W, Kościelak A (2011) Na początku było drzewo. A. Rodak-Śniecińska (ed.). Baobab, Warszawa
28. De Benedetti C, Gerasimenko N, Ravazzi C, Magri D (2022) History of *Tilia* in Europe since the Eemian: past distribution patterns. Rev Palaeobot Palynol 307:104778
29. Eaton E, Caudullo G, de Rigo D (2016) *Tilia cordata*, *Tilia platyphyllos* and other limes in Europe: distribution, habitat, usage and threats. European Atlas of Forest tree Species. Publication Office of the European Union, Luxembourg
30. Yücedag C, Özel HB, Ayan S, Ducci F, Isajev VV, Seho M (2018) Growth characteristics of *Tilia tomentosa* Moench. from different districts in the regions of Marmara and western Black Sea in Turkey. Genetika 51:731–742
31. Pigott CD (2012) Lime-trees and basswoods. Cambridge University Trees, Cambridge
32. Jarić S, Kostić O, Miletić Z, Marković M, Sekulić D, Mitrović M, Pavlović P (2024) Ethnobotanical and ethnomedicinal research into medicinal plants in the Mt Stara Planina region (south-eastern Serbia, Western Balkans). J Ethnobiol Ethnomed 20:7
33. Eastaugh N (2008) Pigment compendium: a dictionary and optical microscopy of historic. Butterworth-Heinemann, Waltham, MA, USA
34. Medić M (1999) Stari slikarski priručnici, Republički zavod za zaštitu spomenika kulture, Beograd, p 290 (**in Serbian**)
35. Konstantas A, Karapanagiotis I, Boyatziz S (2021) Identification of colourants and varnishes in 14th century decorated wood-carved door of the Dionysiou Monastery in Mount Athos. Coatings 11:1087

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