The Scientific Investigation of the Imperial Gates Belonging to Sanmihaiul Almasului Wooden Church (1816)

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In order to preserve and restore the Imperial Gates belonging to the wooden church of Sanmihaiul Almasului, Salaj County, the scientific expertise of the wooden support and of the painting materials (ground, pigments) with FTIR, XRF spectroscopy and gas chromatography-MS. FTIR spectroscopy offers information about the wooden support whereas XRF, FTIR and GC-MS methods were employed for painting materials structural characterization. These structural data can be correlated with the artistic, theological and historical analysis of this religious patrimony object. After obtaining information about wooden support and painting materials the Imperial Gates were 3D digitized using state of the art laser scanning technology. The digital 3D model obtained was restored in virtual environment and converted to an interactive 3D model which can be used for cultural heritage digital dissemination.

Keywords: Orthodox Imperial Gates, lime wood, painting materials, FTIR, XRF spectroscopy, CG-MS, 3D virtual restoration

The wooden church under the patronage of the Archangels St. Michael and Gabriel in Sînmihaiu-Almasului, Salaj County (fig. 1), was built in the Eighteen century, probably not long before being painted. The interior painting was carried out by the painter as shown by the inscription on the right side of the iconostasis … *priest Andrei Toma, painted by Pop Ioan, 1794, January 20* [1]. Based on an older reading of the votive inscription on the left side of the iconostasis (fig. 2), the year 1778 is mentioned as the edification date of the church [2]. The entire structure is constructed from oak, with the large slopes of the roof, which descends steeply toward the altar, having a tower with an open pavilion on sculpted arches at the entrance. The porch is placed on three sides, the north, the south and the west, respecting the sculpted decoration of the pavilion. The painting was made, according to the votive inscription in the year 1794 by the itinerant painter Ioan Pop Româna°i, this being the oldest known work of his and which adorned the whole church, having a somewhat naive character, but respecting the Byzantine iconography [3, 4].

Fig. 1. St. Michael and Gabriel the Archangels wooden church

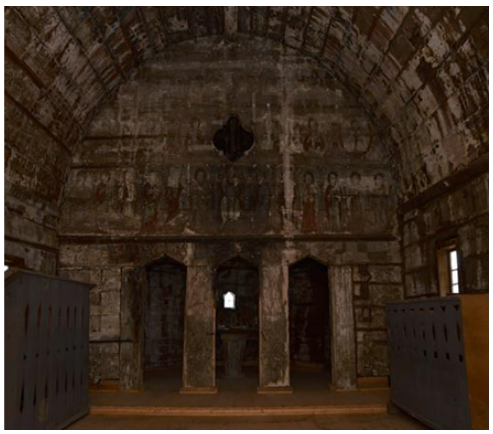

Fig. 2. The iconostasis of St. Michael and Gabriel the Archangels wooden church

The Imperial Gates subjected for investigations (fig. 3) are made from sculpted wood having the pattern of vines with grapes and within each gate three medallions. The scene of the Annunciation is painted on the upper part of the gates, while the four evangelists are painted on the lower part.

The aim of the paper was to investigate the Imperial Gates from Sanmihaiul Almasului wooden church by applying several adequate techniques such as [5-19]: FTIR and XRF spectroscopy, GC-MS spectrometry. 3D scanning techniques were applied to obtain a virtual image (3D model and texture).

Experimental part

X-ray fluorescence measurements were performed using an INNOV-X Alpha-6500 portable instrument (35 kV voltage, 15 μA intensity, 3 mm filter, Be window, 2 square mm spot size and PIN Si detector). Integration time was

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Fig. 3. The Imperial Gates

set for 60 s, in two consecutive runs of 30 s each. XRF measurements were performed in situ. FTIR measurements were performed with a JASCO 6100 spectrometer in the 4000 to 400 cm^{-1} spectral range with a resolution of 4 cm^{-1} employing the KBr pellet technique. The spectra were processed by Spectral Analysis software. EI-MS measurements were performed at 70 eV on Electron Impact Mass Spectrometer of type MAT 311 having direct introduction sample system; mass spectra were obtained in full scan mode, in the mass range 25-650 Daltons. The sample temperature was raised from 250 to 350°C. The collected sample was powered end than placed in n-hexane and after 10 of ultrasound treatment 2µL was injected in GC/MS system, in order to obtain a 3D model and texture of the Imperial Gates, a scanner with structured light was used. The main objective of digitization of the Imperial Gates was to obtain an accurate 3D model for digital restoration of the wooden support.

Results and discussions

XRF

XRF data together with the corresponding sampling are presented in table 1.

Composition of the painting materials based on XRF data: dark red-lead red + Vermillon + red As; open red - red lead + Vermillon + red As; hallo - Au; green - Scheele green; blue - Prussian blue + cobaltite; white - lead white; red garment - red iron + Vermillon; ochre - iron oxide.

FTIR spectroscopy

To determine the wood species, one compares the FTIR spectra of Imperial Gates' wood sample and of the lime one, (fig. 4).

In order to determine wood conservation status of the Sanmihaiul Almasului' Imperial Gates, the crystallinity indexes (defined as [20] I^1cr = A1377/A669, I^2cr = A1109/A690 or as TCI = A1378/A2925) and LOI = A1426/A895)

	Fe	Cu	Zn	As	Au	Hg	Pb
Dark red	1403	123	<LOD	8514	<LOD	7331	45678
Open red	823	102	85	4900	<LOD	2628	23034
dark red-inner frame	1673	203	203	14450	<LOD	17186	80918
leaf-interior model	2277	50	27	20	530	90	51
blue-frame	2147	230	53	4876	<LOD	401	21019
aura-icon	2578	88	40	393	79	1805	1644
blue background-icon	3447	73	43	4226	<LOD	471	17679
white background-icon	3481	265	290	19383	<LOD	2591	122400
red-icon	1594	122	198	2300	<LOD	17024	8938
model-cross edge	3193	55185	8474	112	566	<LOD	552
blue-cross	4221	2275	144	7833	<LOD	804	39140
blue-column	3311	74	62	5639	<LOD	603	24760
blue-exterior	2408	<LOD	<LOD	18940	<LOD	20296	123363
green-leaves	3872	63564	16892	165	<LOD	<LOD	1049
aura-icon	584	58	21	110	247	168	463
red-icon	850	64	140	2029	<LOD	19924	6841
blue-wings	3727	34218	<LOD	5825	<LOD	667	40546
grapes	3602	69	16	36	<LOD	25	116
white-book	3338	309	214	19256	<LOD	1438	152666
green-original	1363	28945	<LOD	3765	<LOD	165	17180
green-rest	1903	9700	<LOD	1461	<LOD	147	6563
wing-original	1064	53	19	59	<LOD	<LOD	312
wing-rest	1259	182	45	59	<LOD	<LOD	327
ochre-original	20283	217	112	10435	<LOD	533	44745
ochre-rest	4952	<LOD	45	<LOD	94	<LOD	167
red-original	2703	<LOD	326	103	<LOD	45086	288
red-rest	2074	<LOD	27	<LOD	<LOD	254	90
grey	1624	<LOD	142	9168	<LOD	412	53066
leaf	1323	111	85	72	1524	440	305
red-original	2272	181	<LOD	16132	<LOD	1511	85206
red-rest	2054	<LOD	30	61	<LOD	<LOD	907
red-garment	11353	<LOD	281	283	<LOD	50135	605

Table 1
XRF DATA FOR THE IMPERIAL GATES SAMPLING POINTS

**Concentration in mg/kg*

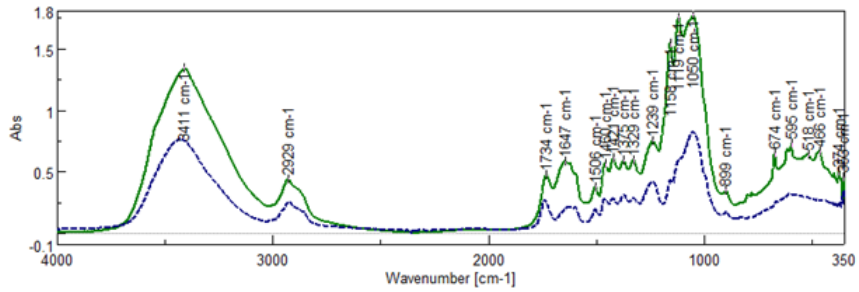

Fig. 4. Legend: solid line – wood from sculpture; dashed line-lime wood sample\

Sample	I^1_{cr}	I^2_{cr}	TCI	LOI	(L/C)1	(L/C)3	(L/C)4
Historical wooden support	-	-	1.35	1.74	0.79	1.07	0.63
Modern lime wood	1.21	3.11	1.25	1.71	0.71	1.15	0.61

Table 2
CONSERVATION STATUS OF LIME WOODEN SAMPLES

were determined. Lignin to cellulose ratios, defined as [21, 22] (L/C)1 = A1506/A1738, (L/C)2 = A1506/A1158 or (L/C)3 = A1506/A895 and (L/C)4 = A1506/A1377 were calculated for wooden samples in agreement to already established definitions. These definitions are used only as a measure of their change during time.

Table 2 contains these parameters determined for historical and modern lime wood species.

The crystallinity is higher for historical lime wood as compared to modern one, see the corresponding values from table 2. The cellulose content is decreased in time more rapidly than lignin one for this wood species, *i. e.* the cellulose consumption is faster that lignin one, see (L/C)1, (L/C)3 and (L/C)4 behaviour.

The presence of Ca oxalate in wood samples was detected, (fig. 5).

In the analysis of the painting materials spectra, the composition obtained could be suggested bellow (fig. 6).

Proposed composition [23]: gypsum (3409, 1623, 1164 and 1117, 612 595 cm^{-1}), aliphatic (2922 and 2851 cm^{-1}), Prussian blue (2091cm^{-1}), egg yolk (~1730, 1650 and 1540 cm^{-1}), lead carbonate (1414 and 680 cm^{-1}), red lead (532 and 471 cm^{-1}), possible silicates (~1044 cm^{-1}).

FTIR spectrum of red frame is presented in figure 7.

Composition [23]: gypsum (3409, 1623, 1164 and 1117, 612 and 595 cm^{-1}), aliphatic (2922 and 2851 cm^{-1}), egg yolk (1738, ~1645, 1544 cm^{-1}), white lead (1409, 676 cm^{-1}), red lead (530 and 463 cm^{-1}).

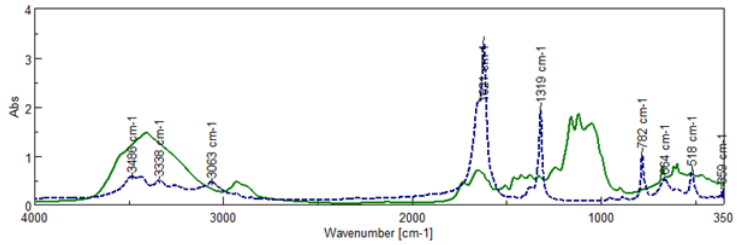

Fig. 5. Legend: solid line - wood with traces of oxalates and gypsum: dashed line - Ca oxalate

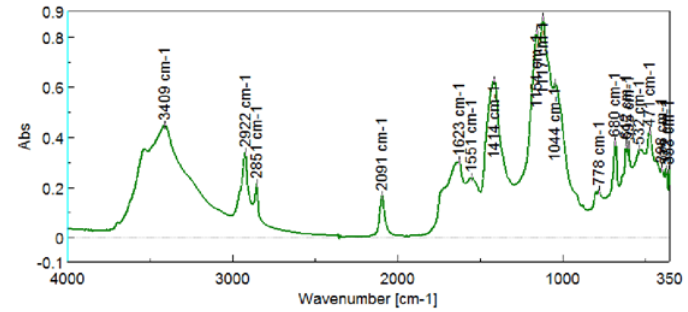

Fig. 6. Legend: blue - frame FIR spectrum

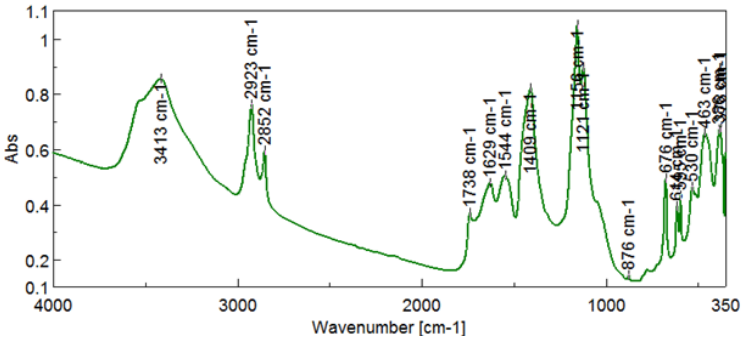

Fig. 7. Red-frame FTIR spectrum

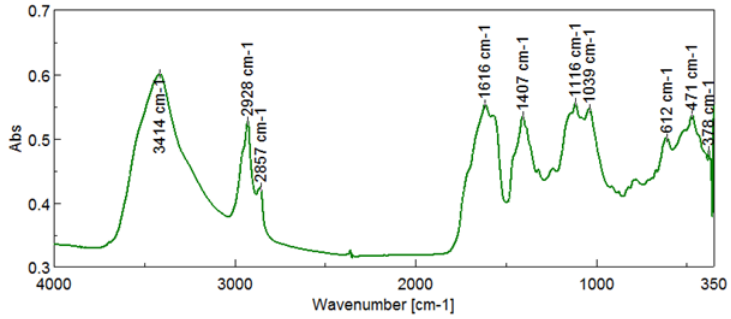

Fig. 8. Metallic green+foil FTIR spectrum: gypsum, aliphatic, white lead, silicates, lead carbonate

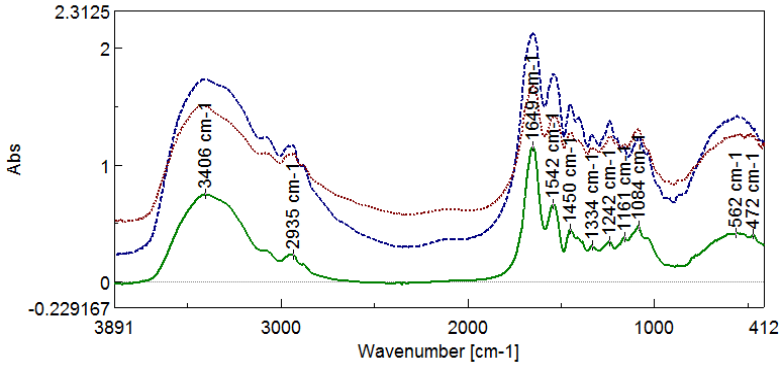

Fig. 9. FTIR spectra of putty (solid line); dashed line-bone putty; dotten line-fish putty; perhaps fish putty

FTIR spectrum of Metallic green+foil is presented in figure 8.

As concerned the putty sample collected from the gates, its FTIR spectrum was compared to the fish and bone ones, (fig. 9).

The protein (1649 and 1542 cm^{-1} bands) is the main component [23].

GC-MS

The mass spectra were obtained by Electron Impact (EI) at 70 eV and the compounds were identified by comparison with mass spectra from data base, (table 3).

From the table 3 one can conclude that the *putty* formulation was obtained as tempera grass (vegetal oil-probable rapeseed and yolk eggs confirmed by cholesterol presence).

Digital restoration

In the case of Imperial Gates digital restoration targeted mainly wood support restoration in two zones where is incomplete as shown in the figure 10.

For digitize the two Imperial Gates a 3D color scanner with structured light was used for 3D shape and color. 3D scanning is an instrument used in various fields from medicine [24] and continuing with archeology and history [25, 26]. The accuracy of the scan result allows use in areas such Formula 1 [27], in training [28] and cultural heritage [29-31].

Digital restoration of Imperial Gates has been approached in [5, 9] where the author shows a method of restoring digital paint layer, after 3D scanning of the imperial Gates the painting layer has been digitally restored and 3D model of the gates was re-textured with a texture map which contain the restored paint layer, (fig. 10).

In the case of the imperial gates from Sanmihaiul Almasului digital restoration was started with the digitization of the two gates, it was made with 3D scanner Go!Scan 20, the scanner resolution : 0.1 mm, allowing us to obtain a 3D model with high resolution. The second step

No	Compound name	Formula	Molecular Weight	Diagnostic
1	n-Hexadecanoic acid	$C_{16}H_{32}O_2$	256	87. 129
2	n-Octadecanoic acid	$C_{18}H_{36}O_2$	284	87. 129
3	2-Monopalmitin	$C_{19}H_{38}O_4$	330	98. 239
4	2-Monostearin	$C_{21}H_{42}O_4$	358	98. 267
5	Cholesterol	$C_{27}H_{46}O$	386	213. 301
6	Campesterol	$C_{28}H_{48}O$	400	213. 315
7	Sitosterol	$C_{29}H_{50}O$	414	213. 329

Table 3
COMPOUNDS DETECTED IN PUTTY SAMPLE FROM SANMIHAIUL ALMASULUI IMPERIAL GATES

Fig. 10. Imperial Gates: left – original, center – wood support digitized, right – both Imperial Gates digitized

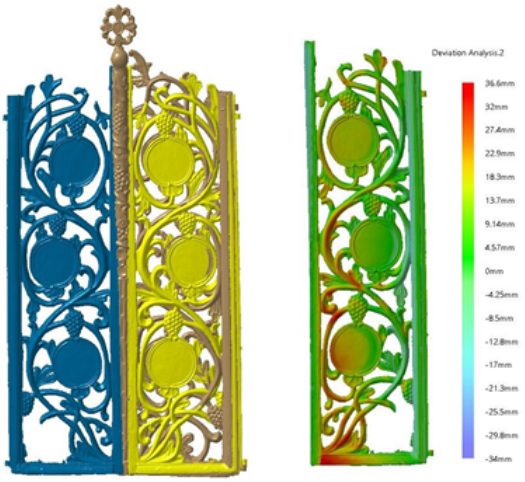

Fig. 11. Imperial Gate: left - left and right model of Imperial Gate overlapping, right – deviation analysis between left and right Imperial Gate

Fig. 12. Wooden support digital restored for Imperial Gate

of the work is the comparison between the two 3D models gate, (left and right) to determine if the sculptor has used a template. Although the two gates seem symmetrical, CAD analysis of the digital models has revealed that the sculptor has used a template but that was pretty much deviated to one of the gates probably due to the configuration of the wood used.

The figure below shows analysis of the deviation between the two gates, there are differences between -34 mm and + 36 mm, so decision was taken that the two missing zones to be modeled manually and using as model the right gate in a manner to obtain an approximately symmetric model but integrate elements of the left gate which are intact.

The figures 11 and 12 present the result of digital restoration of the wood support. The two missing pieces can be manufactured using CNC milling machine for wood, so that after achieving a raw form of the missing part this can be fine processed by a sculptor and integrated into the gate where the gate will be restored in classic way.

Conclusions

The wooden support of the Imperial Gates is of lime grounded with gypsum using as binder fish putty.

The painting manner is of tempera grass (vegetal oil and egg yolk) and the painting materials were: red lead, Vermillon, As red, Prussian blue and cobaltite, Scheele green, lead white, iron ochre and Au foil for halo.

Digital restoration of the Imperial Gates can be done using 3D scanning and CAD software. As shown in the paper the missing part from wood support can be digital restored and the original model can be completed for obtain a 3D model of whole Imperial Gate. After this process the missing part can be painted in digital environment.

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