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A Study on the Prevention of Specular Reflections in 3D Scanning of Glossy Artifacts

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Abstract

Non-contact 3D scanners, which are commonly used for 3D recordings in the field of cultural heritage, use optical technology that relies on light. However, when applied to glossy or dark surfaces, such as those of glass and metal, these scanners often generate data errors due to light reflection and absorption. In practice, such limitations have been documented during the scanning of Korean cultural heritage objects of various materials, including Buddhist sculptures, white porcelain, and celadon, thereby presenting significant challenges to the establishment of comprehensive 3D heritage databases. To address these challenges, this study evaluated the material safety and applicability of naturally vanishing scanning sprays in the 3D scanning of glossy artifacts. The material safety test results for the spray were judged to be 'permanent', and no noticeable physical or chemical changes were observed on the specimen surface before and after spray application. Furthermore, no significant differences were found in the resulting 3D scan data based on the type of spray or the material of the scanned object. These findings confirm both the material safety and the practical applicability of vanishing scanning sprays in the context of cultural heritage. Based on the results, this study suggests that such sprays can be effectively used to minimize surface damage while improving the accuracy of 3D scan data in real-world documentation of glossy heritage surfaces.

1. Introduction

Three-dimensional (3D) technologies have been actively employed worldwide in various sectors of cultural heritage preservation, including digital documentation, virtual restoration, and digital content development. Among these efforts, digital documentation using 3D scan data has become a core initiative in the digital heritage field, serving as a critical source for the preservation and restoration of cultural properties (Ahn and Kim, 2016).

In Korea, preservation policies emphasize maintaining the original condition of artifacts during 3D scanning and, therefore, recommend the use of non-contact scanning methods to minimize surface damage. However, non-contact optical scanning systems are sensitive to material properties and lighting conditions, often resulting in data variations or errors. In particular, glossy or dark surfaces—such as those of metal or glass—pose significant challenges due to light reflection and absorption (Hongwei Zhang et al., 2012). Glossy artifacts, including metal and ceramics, account for over 10% of Korea's cultural heritage, and due to the historical development of lacquer and printing technologies, the proportion of dark-surfaced artifacts is also relatively high. As a result, difficulties have been reported in obtaining accurate 3D scan data from diverse cultural objects such as Buddhist statues, white porcelain, celadon, and lacquerware (Kim et al., 2022), creating obstacles to the construction of comprehensive 3D cultural heritage databases (Moon and Lee, 2024).

To address these limitations, several strategies have been proposed in the field of heritage conservation, including the use of alternative scanning devices, photogrammetry, and post-processing techniques. However, these methods often require significant time and cost and also raise concerns about potential data distortion during post-processing (Khong and Mhd Pauzi, 2022). Conversely, the industrial sector has adopted more direct approaches to improving scan accuracy, such as powder coatings and silicone molding. Among these, scanning sprays composed of fine powders are widely used due to their ease of application and accessibility. Naturally vanishing scanning sprays, in particular, offer a significant advantage: the spray evaporates after a short time, eliminating the need for physical removal and minimizing potential surface damage prior to scanning. Despite their widespread use, no prior studies have systematically evaluated the toxicity or potential surface effects of vanishing scanning sprays on scan objects. Consequently, the safety and material compatibility of these sprays for cultural heritage applications remain largely unverified.

This study aims to evaluate the material safety of vanishing scanning sprays when applied to cultural heritage objects, in order to assess their feasibility for use in 3D scanning workflows and to propose an approach that minimizes damage to artifact surfaces while enhancing scanning accuracy.

2. Materials and Methods

2.1 Selection of Test Materials

Three widely used anti-glare scanning sprays for 3D scanning were selected, and their characteristics—including evaporation time, coating color, and gloss—were compared. Preliminary tests were performed on plastic, ceramic, and glass specimens to assess their practical performance and validate their effectiveness (Figure 1).

2.2 Specimens

To evaluate the applicability of spraying cultural properties, two types of samples were prepared: metal samples and glossy surface samples. The metal samples used for the material safety assessment were selected as copper (Cu 99.9%, thickness 0.1 mm), iron (Fe 99.9%, thickness 0.1 mm) and lead (Pb 99.9%, thickness 0.1 mm), which are components that can be confirmed in bronze and iron artifacts. They were prepared in a size of 3 × 4 cm each to increase the stability of the samples (Table 1). The glossy surface samples for the applicability assessment were selected considering the materials that make up most of the Korean artifacts. Considering the ease and stability of analysis, copper (thickness 0.3 mm), porcelain (thickness 0.5 mm), and

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glass (thickness 0.5 mm) specimens were produced (Table 2).

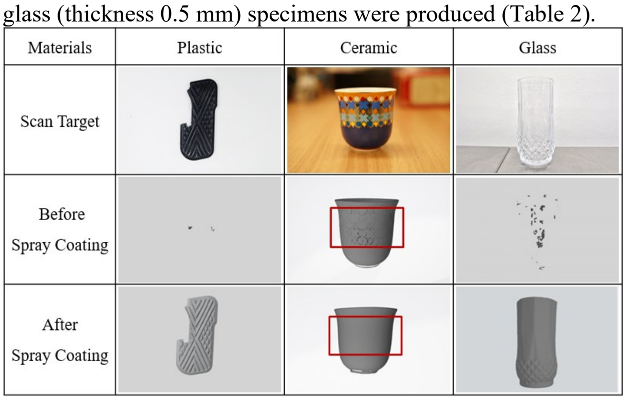

Figure 1. Preliminary test results.

Materials	Copper (Cu)	Iron (Fe)	Lead (Pb)
Blank	Cu-N	Fe-N	Pb-N
A	Cu-A	Fe-A	Pb-A
B	Cu-B	Fe-B	Pb-B
C	Cu-C	Fe-C	Pb-C

Table 1. Metal specimen

Materials	Copper(C)	Porcelain(P)	Glass(G)
Blank	CN	PN	GN
A	CA	PA	GA
B	CB	PB	GB
C	CC	PC	GC

Table 2. Glossy surface specimen

2.3 Evaluation of Material Safety

To evaluate the potential risk of surface damage when spraying cultural heritage artifacts, the Oddy test, one of the safety evaluation methods for exhibit materials, was performed on metal specimens. Each test jar was coated with spray and sealed with a Teflon-taped cap containing a vial of distilled water and metal specimens (copper, iron, lead). The sealed jars were stored at 60°C in a constant temperature chamber (JSRH-500CP, JS Research, KOR) for 28 days, as illustrated in Figure 2. The condition of each metal specimen was monitored weekly and compared to a blank sample after 28 days. In addition, weight and color changes before and after the test were measured. The measurement results were evaluated according to the 3 in 1 Oddy test protocol such as Table 3: Implemented by international institutions such as the British Museum, IPERION HS in Europe, and the Metropolitan Museum of Art.

Category	Evaluation Criteria
Permanent	No significant discoloration or weight change observed on the test samples.
Unsuitable	Corrosion is observed on two or more types of test samples.
Temporary	Temporary use is recommended depending on the extent of corrosion and weight variation.

Table 3. British Museum's 3 in 1 Oddy test protocol

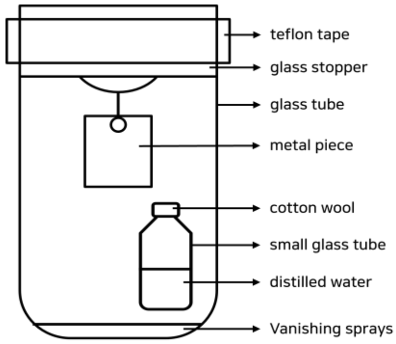

Figure 2. Methods of Oddy test.

2.4 Evaluation of Surface Effects

2.4.1 Physical Characteristics: To evaluate changes in the physical properties of the specimens, digital microscopy was performed after spray evaporation. Subsequently, UV fluorescence was assessed using the built-in UV light source to examine the surface condition and detect any potential residues. For more precise comparison, color measurements were obtained before and after spray application using a spectrophotometer. The color difference (ΔE*ab) was calculated according to the standards of the American National Bureau of Standards (NBS) (Table 4). In addition, subtle weight variations were measured before and after spraying with a precision balance.

ΔE*ab	Category	Calculation formula
0~0.5	trace	$\Delta E^*ab = [(\Delta L^*)^2+(\Delta a^*)^2 +(\Delta b^*)^2]^{1/2}$
0.5~1.5	slight	
1.5~3.0	noticeable	
3.0~6.0	appreciable	
6.0~12.0	much	
upper 12.0	very large	

Table 4. NBS color difference chart

2.4.2 Chemical Characteristics: Portable X-ray fluorescence spectroscopy (P-XRF) was used to analyze chemical changes on the specimen surfaces caused by the sprays. In addition, the spray coatings were observed under a scanning electron microscope (SEM), and the surfaces before and after application were compared. Energy-dispersive X-ray spectroscopy (EDS) was used to analyze the chemical composition of the coatings and assess any compositional changes after evaporation. The equipment and instruments used in the experiment are listed in Table 5.

Equipment	Model Name
Digital Microscope	Dino-Lite Edge (Anmo electronics, TW)
Ultraviolet Microscope	
Spectro colorimeter	CM-700d (Minolta, JP)
Analytical Balance	CP224S (Sartorius, DE)
X-ray Fluorescence spectroscopy(P-XRF)	Vanta C-series (Olympus, JP)
Scanning Electron Microscope (SEM)	SU3800(Hitachi, JP)
Energy-Dispersive X-ray Spectroscopy (EDS)	Ultim Max EDS detectors (Oxford, GB)

Table 5. Equipment and instruments list

2.5 Evaluation of 3D Scan Data Effects

To assess how the spray coatings affect 3D scan data accuracy, an effect assessment was conducted using actual objects with glossy surfaces.

2.5.1 Analysis of Spray Coating Properties: The spray coatings were applied under controlled conditions to examine factors that could affect scan results. Each glossy specimen was divided into three sections, and spraying durations of 5, 10, and 15 seconds were applied. Spraying conditions were fixed at a 90° angle and 15 cm distance. The test variables included spray type, spraying duration, and specimen material. Observational parameters included coating thickness and coating color (Table 6).

Comparison Conditions		Observed Properties
Spray type	A	Coating Thickness/ Coating Color
	B	
	C	
Material	Copper	
	Porcelain	
	Glass	
Spraying Time	5 seconds	
	10 seconds	
	15 seconds	

Table 6. Comparison of coating characteristics

2.5.2 Comparison of 3D Scan Data: Based on the results of the coating analysis, the vanishing scanning sprays were applied to test objects composed of materials analogous to the glossy specimens, including bronze, porcelain, and glass, as shown in Figure 6. Comparison variables included spray type and number of spray applications. Each object was scanned three times using a structured-light 3D scanner (Einscan PRO HD, Shining 3D, CHN) mounted on a turntable. Scanned data before and after spraying were aligned using the ICP (Iterative Closest Point) algorithm and compared using C2M (Cloud-to-Mesh) distance analysis. This method calculates the shortest distance from each point in the pre-spray point cloud to the post-spray mesh surface. The deviations were visualized with a color scale to indicate localized protrusions or recessions. Mean and standard deviation values were extracted to evaluate surface consistency and quantify whether the spray introduced measurable geometric variations.

Figure 3. Scanning subject.

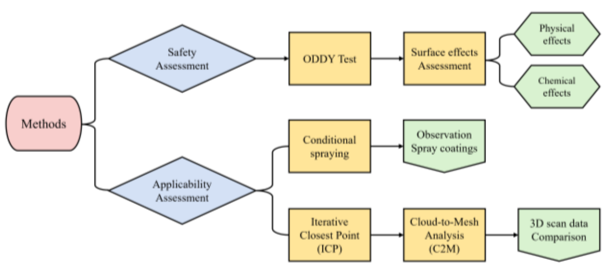

Figure 4. Overall workflow.

3. Results and Discussion

3.1 Results of the Oddy Test

After 28 days of exposure, no visible corrosion or discoloration was observed on any of the metal specimens, as shown in Figure 5. Micro-weight measurements revealed that copper (Cu), iron (Fe), and lead (Pb) specimens exhibited minimal weight changes, ranging from 0.001 to 0.007 g, corresponding to an average variation of approximately 0.2%, as presented in Figure 6. Color difference (ΔE*ab) measurements showed low values of less than 1.5 compared to the pre-experiment state, as illustrated in Figure 7.

Based on these results, no significant material degradation due to the vanishing scanning sprays was observed, and the outcome is considered to be classified as ‘permanent’.

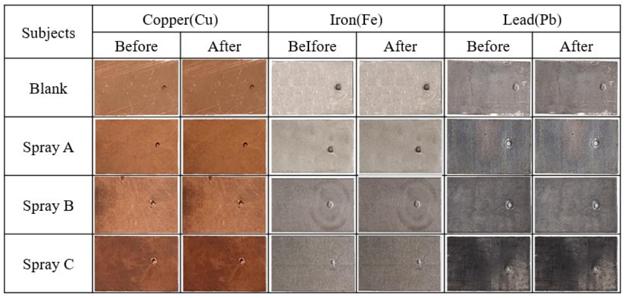

Figure 5. Oddy test results.

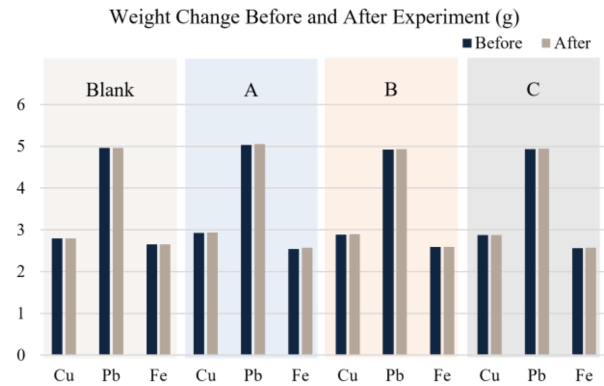

Figure 6. Results of micro-weight measurements.

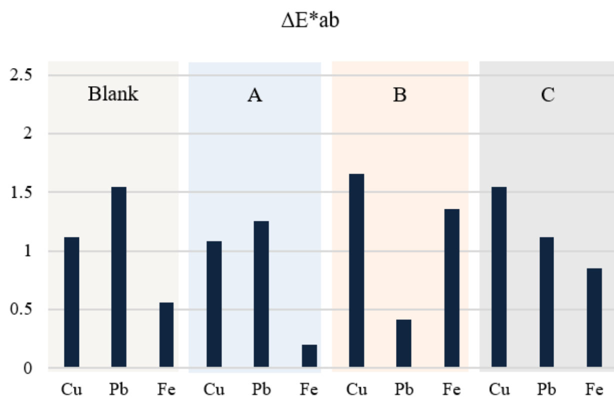

Figure 7. Color measurement results.

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3.2 Observations of Physical Property Changes

3.2.1 Microscopic observation: Immediately after spray application, a white powdery layer, presumed to be the coating, was observed on the specimen surface under a digital microscope. However, no residue remained after evaporation, and no notable surface alterations were detected compared to the pre-application state. Additionally, none of the sprays (A, B, or C) exhibited UV fluorescence. As shown in Figure 8, these results suggest that the likelihood of surface damage caused by residual materials after spray evaporation is very low.

3.2.2 Micro weight measurements: Weight measurements conducted immediately after spray application showed an increase of approximately 0.03–0.06 g relative to the pre-application weight. Following evaporation, the recorded weights returned to their original values (Table 7). The overall weight variation was minimal, averaging approximately 0.03%, indicating that the impact of the spray on the specimens is negligible.

3.2.3 Color difference: All three sprays initially exhibited a high color difference (ΔE*ab > 6.0) immediately after application. However, the ΔE*ab values decreased to below 0.5 after evaporation, indicating that the specimen surfaces had reverted to a state nearly identical to their original color (Figure 9). No significant differences in color change were observed across specimen types or spray quantities. These findings suggest that vanishing scanning spray cause minimal physical alteration to the specimen surfaces.

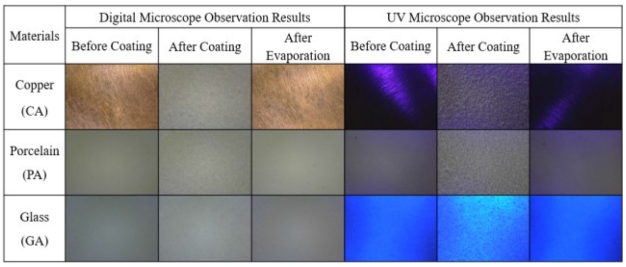

Figure 8. Microscopic observation results (spray A).

Specimen Type		Weight (g)		
		Before Coating	After Coating	After Evaporation
A	Copper (CA)	1.8445	1.8712	1.8447
		-	+0.03	-0.03
	Porcelain (PA)	2.8977	2.9477	2.8984
		-	+0.05	-0.05
	Glass (GA)	5.4942	5.5552	5.4952
		-	+0.06	-0.06
	Average Weight Change		**+0.04**	**-0.04**
B	Copper (CB)	1.7979	1.8244	1.8001
		-	+0.03	-0.03
	Porcelain (PB)	2.8926	2.9370	2.8947
		-	+0.04	-0.04
	Glass (GB)	5.2762	5.3402	5.2764
		-	+0.06	-0.06
	Average Weight Change		**+0.04**	**-0.04**
C	Copper (CC)	1.7657	1.7964	1.7681
		-	+0.03	-0.03
	Porcelain (PC)	2.6196	2.6502	2.6198
		-	+0.03	-0.03
	Glass (GC)	5.5836	5.6502	5.5848
		-	+0.06	-0.06
	Average Weight Change		**+0.04**	**-0.04**

Table 7. Results of micro-weight measurements

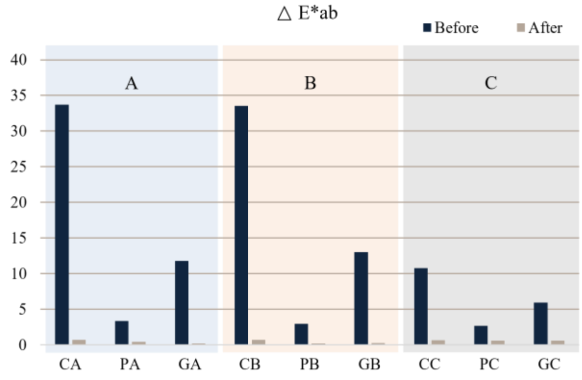

Figure 9. Changes in color values before and after spraying.

3.3 Observations of Chemical Property Changes

As shown in Figures 10 and 11, P-XRF analysis revealed no significant changes in the surface elemental composition before and after spraying, nor were differences observed among the three spray types. In contrast, SEM-EDS analysis conducted immediately after application revealed a white substance covering the specimen surface. EDS mapping confirmed the distribution of carbon (C) within this layer, and point analysis detected carbon content exceeding 70% (Figure 12). These results indicate that the white substance corresponds to a spray film composed of hydrocarbon-based organic compounds, with all sprays (A, B, and C) exhibiting similarly high carbon contents. However, SEM-EDS analysis performed after evaporation detected no residual carbon, and no white substance was observed. As shown in Figure 13, these findings confirm that the spray left no detectable changes in surface composition or morphology, suggesting minimal chemical interaction between the vanishing scanning spray and the specimen surface.

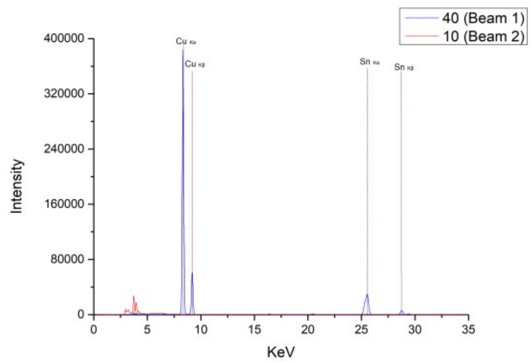

Figure 10. XRF results (Before spray A coating).

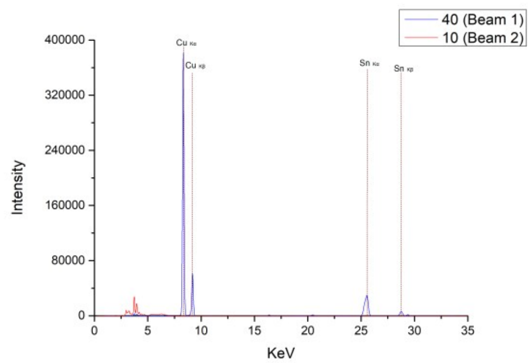

Figure 11. XRF results (After spray A evaporation).

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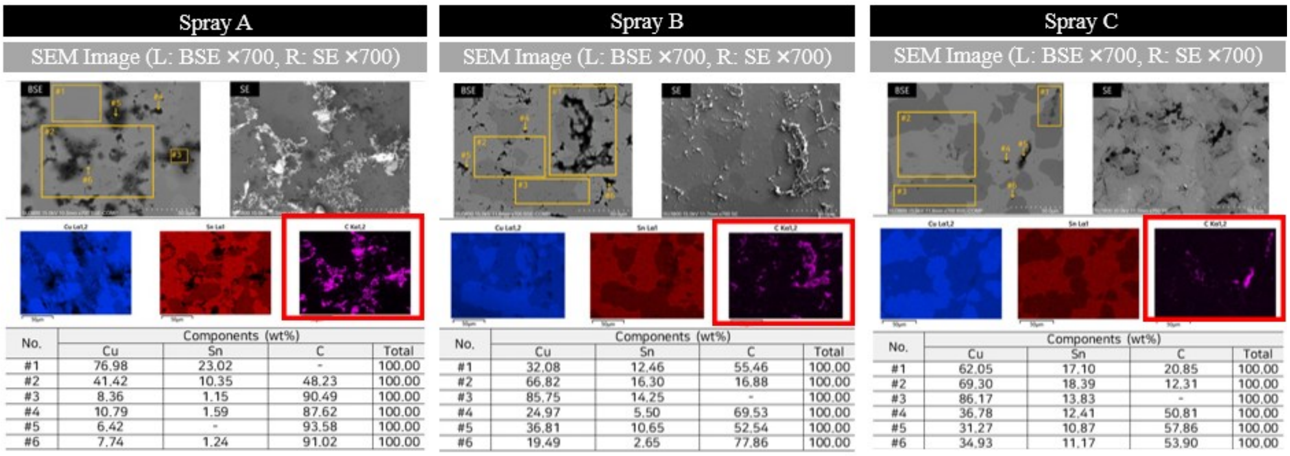


Spray A

No.	Components (wt%) Cu	Sn	C	Total
#1	76.98	23.02	-	100.00
#2	41.42	10.35	48.23	100.00
#3	8.36	1.15	90.49	100.00
#4	10.79	1.59	87.62	100.00
#5	6.42	-	93.58	100.00
#6	7.74	1.24	91.02	100.00

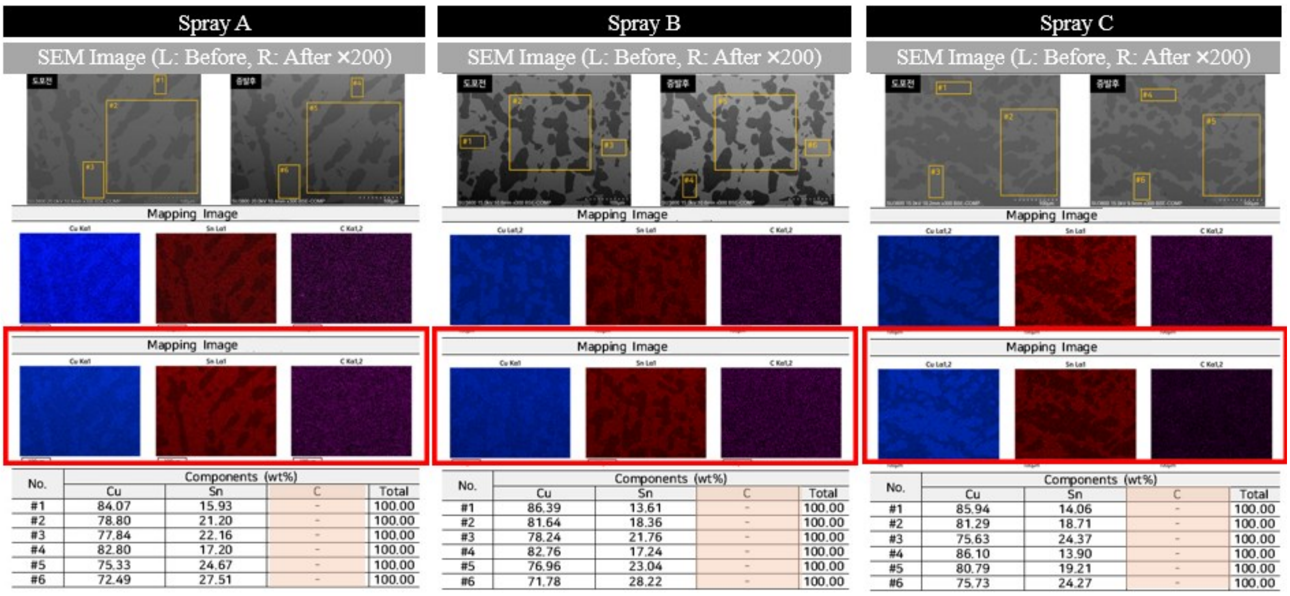
Spray B

No.	Components (wt%) Cu	Sn	C	Total
#1	32.08	12.46	55.46	100.00
#2	66.82	16.30	16.88	100.00
#3	85.75	14.25	-	100.00
#4	24.97	5.50	69.53	100.00
#5	36.81	10.65	52.54	100.00
#6	19.49	2.65	77.86	100.00

Spray C

No.	Components (wt%) Cu	Sn	C	Total
#1	62.05	17.10	20.85	100.00
#2	69.30	18.39	12.31	100.00
#3	86.17	13.83	-	100.00
#4	36.78	12.41	50.81	100.00
#5	31.27	10.87	57.86	100.00
#6	34.93	11.17	53.90	100.00

Figure 12. Elemental analysis results of the surface immediately after spray application.



Spray A

No.	Components (wt%) Cu	Sn	C	Total
#1	84.07	15.93	-	100.00
#2	78.80	21.20	-	100.00
#3	77.84	22.16	-	100.00
#4	82.80	17.20	-	100.00
#5	75.33	24.67	-	100.00
#6	72.49	27.51	-	100.00

Spray B

No.	Components (wt%) Cu	Sn	C	Total
#1	86.39	13.61	-	100.00
#2	81.64	18.36	-	100.00
#3	78.24	21.76	-	100.00
#4	82.76	17.24	-	100.00
#5	76.96	23.04	-	100.00
#6	71.78	28.22	-	100.00

Spray C

No.	Components (wt%) Cu	Sn	C	Total
#1	85.94	14.06	-	100.00
#2	81.29	18.71	-	100.00
#3	75.63	24.37	-	100.00
#4	86.10	13.90	-	100.00
#5	80.79	19.21	-	100.00
#6	75.73	24.27	-	100.00

Figure 13. Comparative analysis of surface composition before and after spray application.

3.4 Evaluation of the Impact on 3D Scanning

3.4.1 Spray Coating Characteristics: All colored sprays exhibited high brightness values (L*) exceeding 80, and the average brightness increased by more than 20 compared to the pre-application state, as shown in Figure 14. The coating thickness was found to be proportional to the brightness level. However, the thickness of the coatings—ranging from 18 to 54 µm after a single application—was within the resolution limit of typical structured-light 3D scanners, suggesting minimal geometric deviation when used appropriately. With controlled application duration and number of sprays, the geometric deviation caused by the coating appeared negligible, as illustrated in Figure 15.

3.4.2 Comparison of 3D Scan Data: When comparing the 3D scan data before and after spray application, the average distance difference was 0.57 mm, and the standard deviation was 1.34 mm. When the scan data were classified by spray type, the average distance difference was 0.04 mm, and the standard deviation was 0.26 mm, as presented in Figure 16. These results suggest that the coating layer has little or no effect on the scan geometry and that the differences depending on the spray type and specimen material are minimal (Juan Moyano et al, 2020).

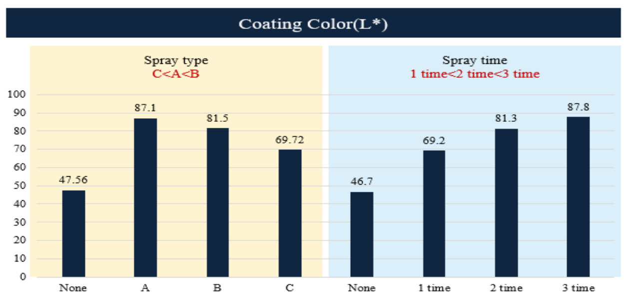


Figure 14. Coating color observation results.

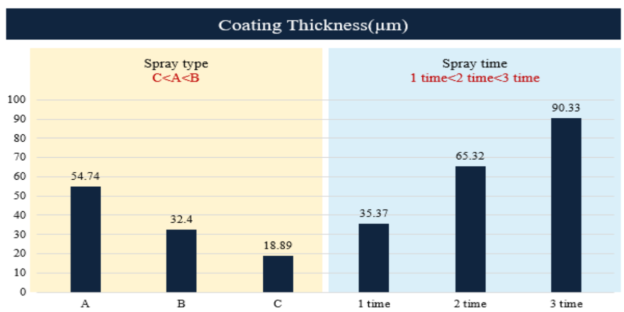


Figure 15. Coating thickness observation results.

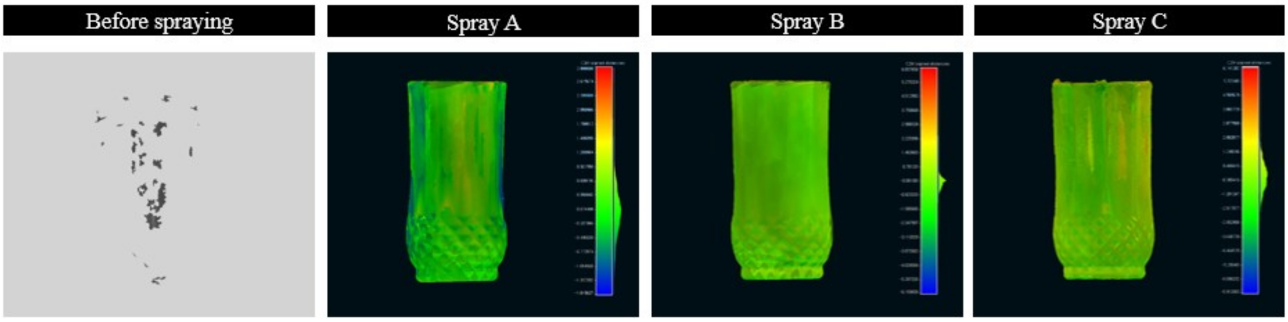


Figure 16. Comparison results of scanning data before and after spray application.

4. Conclusions

In the field of cultural heritage conservation, non-contact 3D scanning has become an essential tool for documentation and restoration. However, glossy surfaces—such as those on metal, porcelain, lacquerware, and glass—often present challenges for optical scanning due to light reflection and absorption. These difficulties are particularly pronounced in Korea, where such materials constitute a significant proportion of movable heritage. This study evaluated the potential application of vanishing scanning sprays, widely used in industrial settings, as a solution to minimize scanning errors on glossy heritage materials. Through comprehensive assessments—including material safety evaluation, surface property analysis, and 3D scan accuracy testing—the feasibility of applying these sprays to cultural artifacts was confirmed.

Oddy test results indicated no corrosion or discoloration on copper, iron, or lead specimens after spray application. Additionally, no significant physical or chemical changes were observed on copper, porcelain, or glass specimens, and no residue remained after evaporation. This suggests a low risk of long-term contamination or surface interference. SEM-EDS and XRF analyses further confirmed that the elemental composition of the surfaces remained unchanged. While carbon was detected in the coating immediately after application, it was absent following evaporation, supporting the material safety and reversibility of the spray.
In terms of 3D scanning performance, vanishing sprays effectively reduced surface reflectivity and improved scanning accuracy. Geometric deviations between pre- and post-application scans were minimal (average ~0.04 mm), well within the standard precision range (0.06–0.07 mm) of structured-light scanners. The spray coating thickness, measured at 18–55 µm, also remained below thresholds likely to impact scanning accuracy under proper application conditions.

Collectively, these results indicate that vanishing scanning sprays are suitable for use on a wide range of cultural heritage materials, including metal, gilded surfaces, lacquerware, glazed ceramics, and glass. Unlike conventional coatings that require physical removal, these sprays evaporate naturally without leaving residues, eliminating the risk of surface abrasion or contamination. Their accessibility, convenience, and optical performance suggest that vanishing sprays represent a practical and reliable tool for cultural heritage 3D documentation in field applications.
However, this study also identified variations in spray behavior depending on material type, spraying range, and application time. Further research is needed to clarify the causes of these variations and to develop quantitative guidelines for optimal use under diverse conditions. Detailed analyses, including trace component assessment, are essential to ensure the sprays' safety for actual cultural artifacts. Moreover, applicability studies on artifacts with diverse characteristics—such as varying surface properties, sizes, degrees of deterioration, and composite materials—are recommended to broaden potential use cases. Finally, further studies are required to verify the practical utility of vanishing sprays under variable environmental conditions, including fluctuations in humidity and temperature, particularly in the context of fieldwork for the analysis and conservation of outdoor cultural heritage.

In conclusion, this study demonstrates that vanishing scanning sprays offer a safe, effective, and non-invasive method for enhancing the accuracy of 3D scans of glossy cultural heritage artifacts. Their broad applicability and chemical stability position them as a promising solution for national and international heritage documentation initiatives.

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