

AI-assisted conservation of Korean paintings and radiation-accelerated aging of the painting substrates

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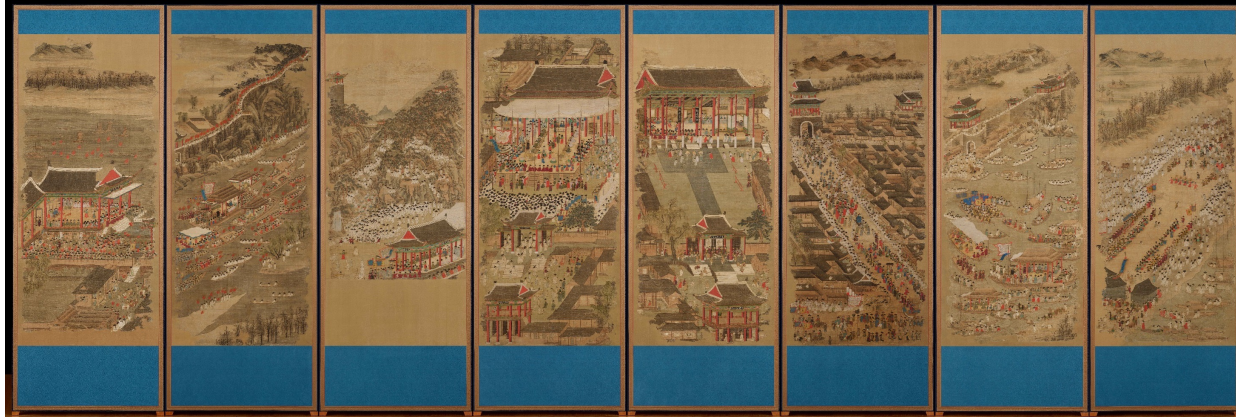


Panel 4 (detail), after conservation.

Artist in Korea, Welcoming Banquet of the Governor of Pyeongan, early 1800s. Ink and color on silk and wood. Museum Purchase, made possible in part by W.C. Endicott and George A. Peabody, 1927. E20262.A-H. Peabody Essex Museum.



Joseon: a kingdom *obsessed with recording* !



Welcoming Banquet of the Governor of Pyeongan, ink and colour on silk, after conservation

Joseon dynasty, 1392 to 1897

a record-keeping culture: dress, rank, buildings, animals, even the weather

2 to 12 panels, one continuous scene

banquets, examinations, diplomatic receptions

Painted on silk, hwa-gyeon

a fine plain weave, vulnerable to insects and humidity



Panel 1: the two top candidates, in graduates' dress

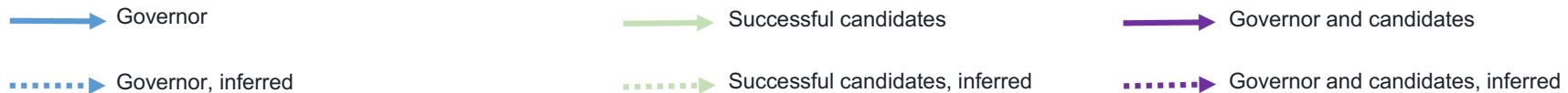
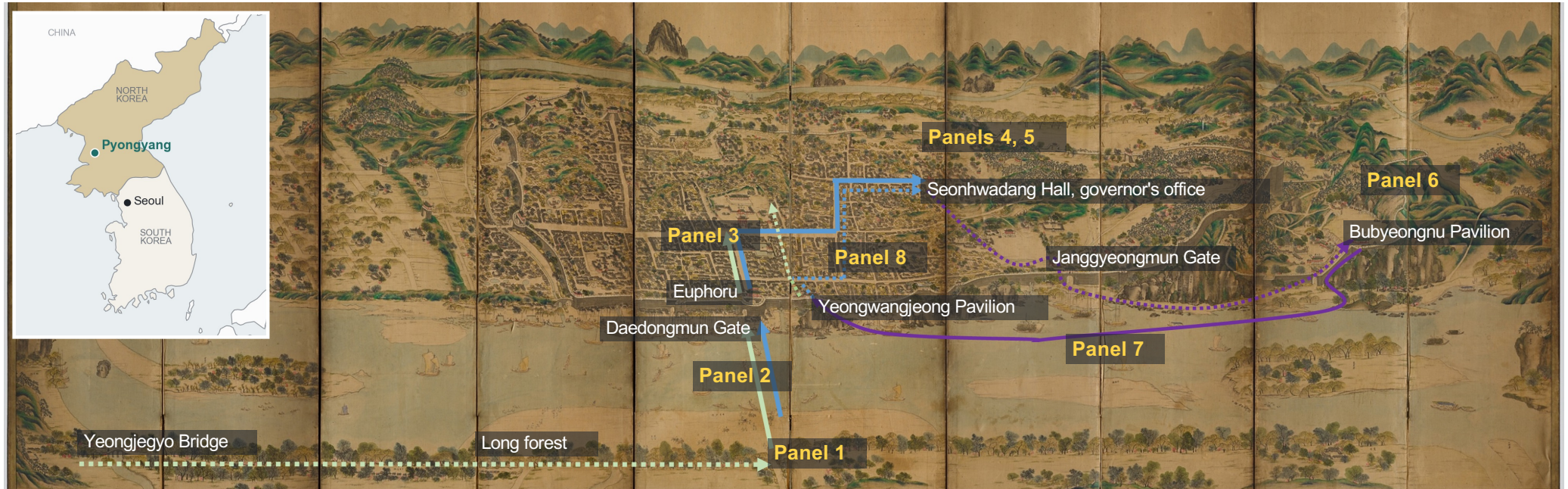


Panel 5: officials seated by rank; the candidates bow



Panel 4: a rainy day: rain hats, covered food trays

The screen follows a real route through Pyongyang

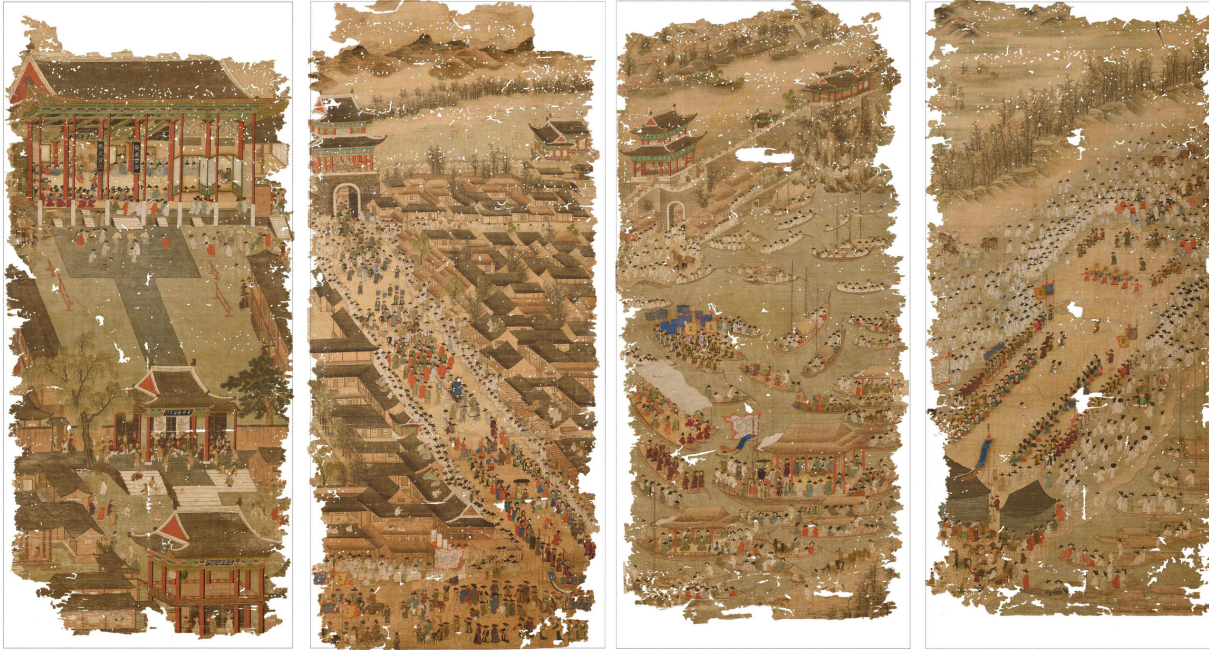


Solid lines: routes confirmed in the panels; dotted lines: inferred. Routes after Leeum, 4th International Symposium on Conservation and Restoration of Overseas Korean Cultural Heritage, 2025. Base map: Map of Pyongyang Fortress (Pyeongyangseongdo), Joseon, ink and colour on cotton, 163.5 × 377.5 cm, National Museum of Korea. Inset: Natural Earth.

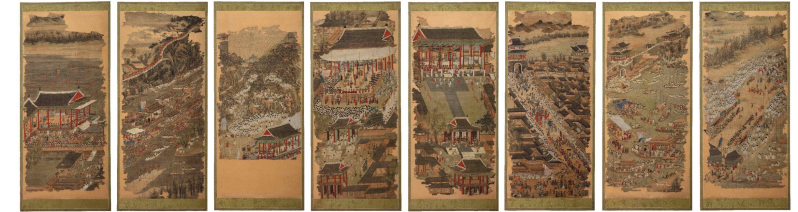
Pyongyang, now the capital of North Korea. The panel labels show how the scenes relate to places on this historical map.

The eight panels arrived separately. The routes of the governor and the successful candidates helped establish their order.

Welcoming Banquet of the Governor of Pyeongan, and its damage



Four of the eight panels after the old backing paper was removed. The exposed losses appear white in this image.



Before conservation, all eight panels in the earlier mounting



Insect damage, humidity, mould: the silk itself is missing

Early 1800s. A celebration hosted by the Governor of Pyeongan for men who passed the civil examination.

Collection of the Peabody Essex Museum, USA (PEM E20262.A-H). Conserved at Leeum under a programme run with the Overseas Korean Cultural Heritage Foundation to conserve Korean heritage held abroad. Shown at Leeum in spring 2025, now on display at PEM.

Displaced overseas in the modern period, like many Korean paintings.

About 10,000 losses, filled by hand

≈10,000

separate losses across eight panels

- Each loss: traced, cut from artificially aged silk, pasted, and fitted.
- Pasting and fitting need a conservator's hands.
- Tracing and cutting are repetitive. For 10,000 losses, they took months.

**Can a computer program trace and cut,
so that conservators can focus on fitting?**



1 Tracing the loss



2 Cutting aged silk

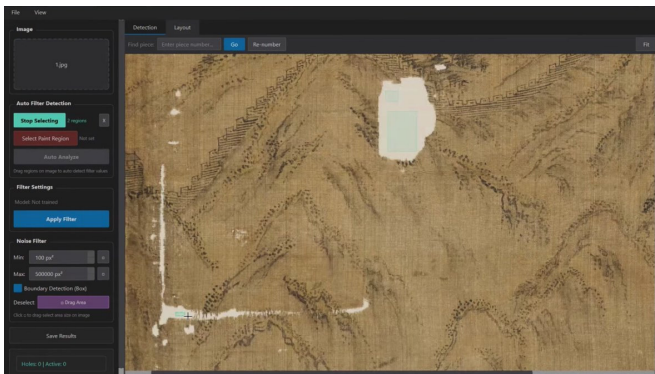
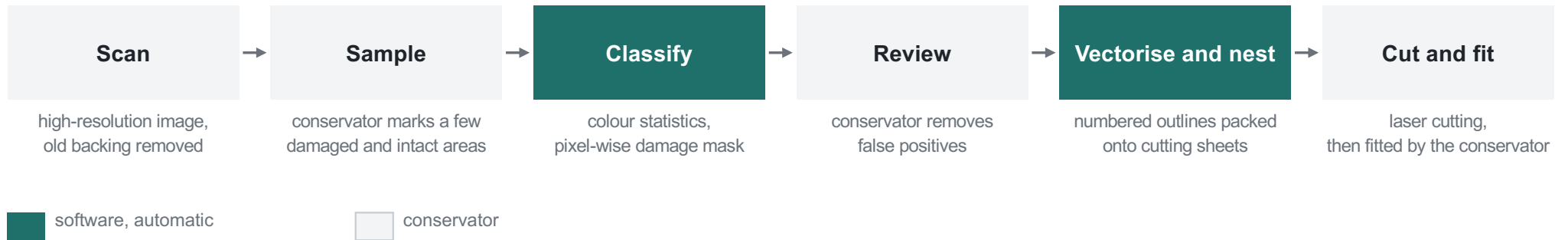


3 Applying paste



4 Fitting the piece

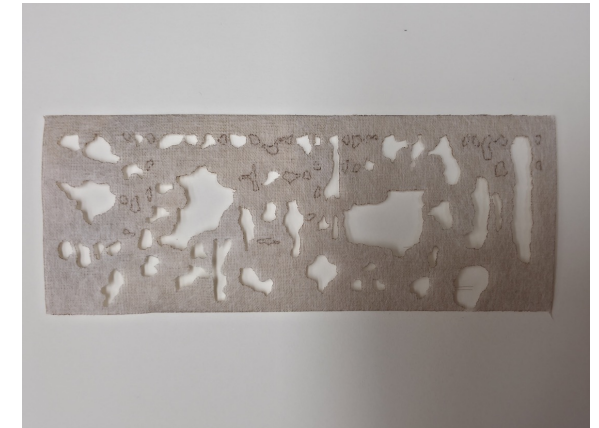
System overview: from scan to laser-cut infills



Desktop application: sampling and detection



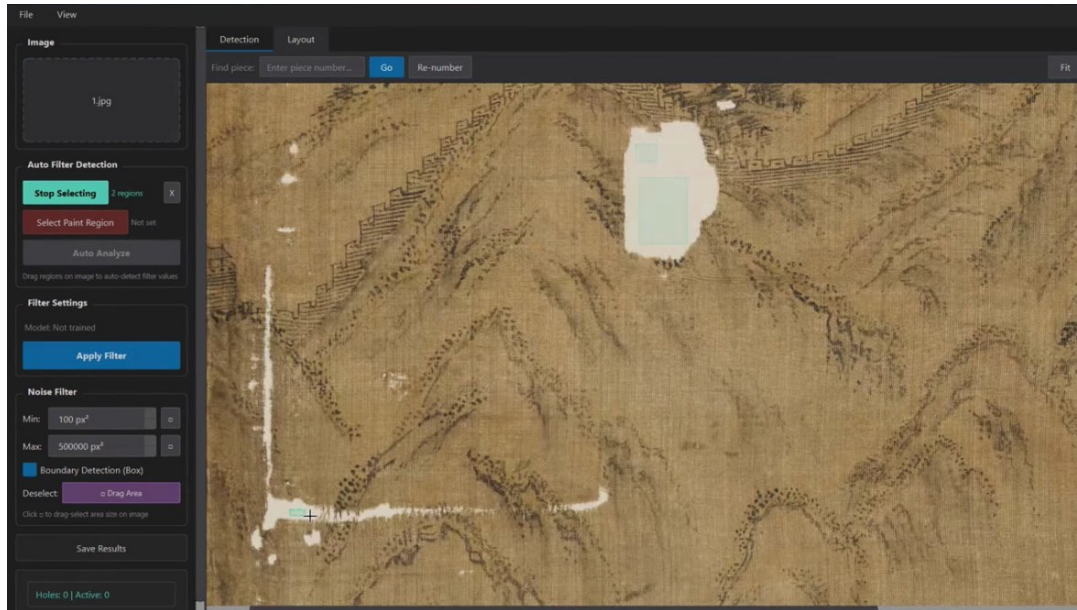
Cutting layout, SVG



Aged silk sheet after the laser-cut pieces were removed

Runs on an ordinary PC. No pre-existing training dataset: the model is fitted to samples from each painting in a few minutes.

Sampling and colour statistics: a conservator trains the model in a few minutes



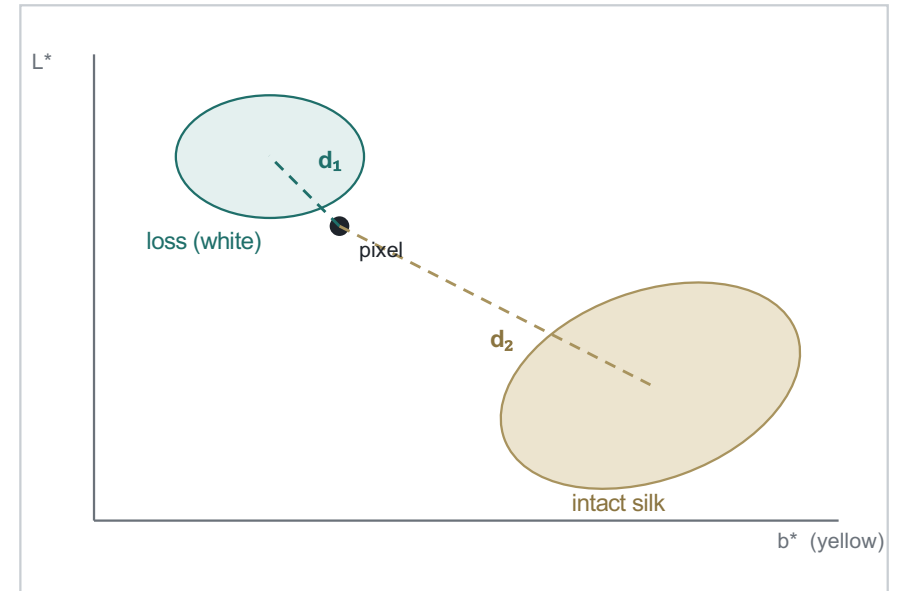
A conservator drags boxes over losses (green) and over intact painting. These pixels are the only training data.

Pixels in CIE-LAB plus saturation: four dimensions.

A Gaussian mixture is fitted to the loss samples, another to the intact samples.

Each pixel goes to the class whose nearest component is closer in Mahalanobis distance.

Clean-up: morphological closing, Gaussian blur, threshold. The weave grid is removed in the frequency domain.



Schematic, two of the four dimensions, one component per class shown.

Ellipses: one standard deviation. L^* increases upward.

Mahalanobis distance accounts for the spread and the correlations of each cluster:

$$d^2 = (x - \mu)^T \Sigma^{-1} (x - \mu)$$

$d_1 < d_2 \rightarrow$ the pixel is a loss.

Several components per class capture the colour variation of aged silk.



Detection and review



Myohyangsan Jeondo, panel 2, old backing removed (scan)

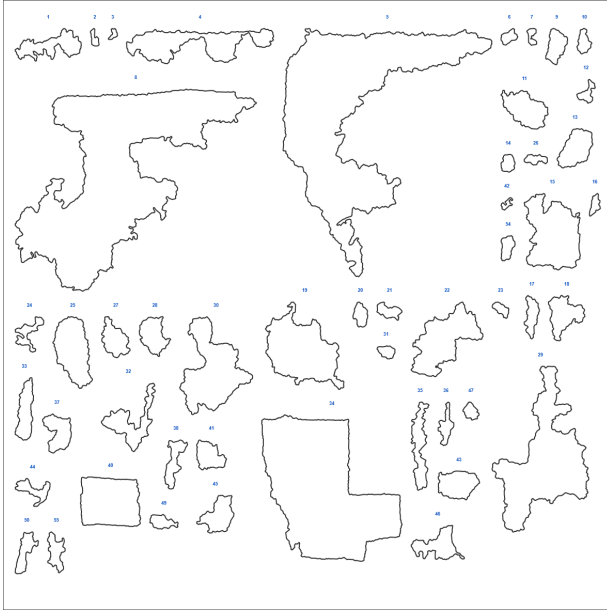


Detected losses, outlined in red. Six losses in this area, 71 on the panel. Spots below the minimum area are ignored.

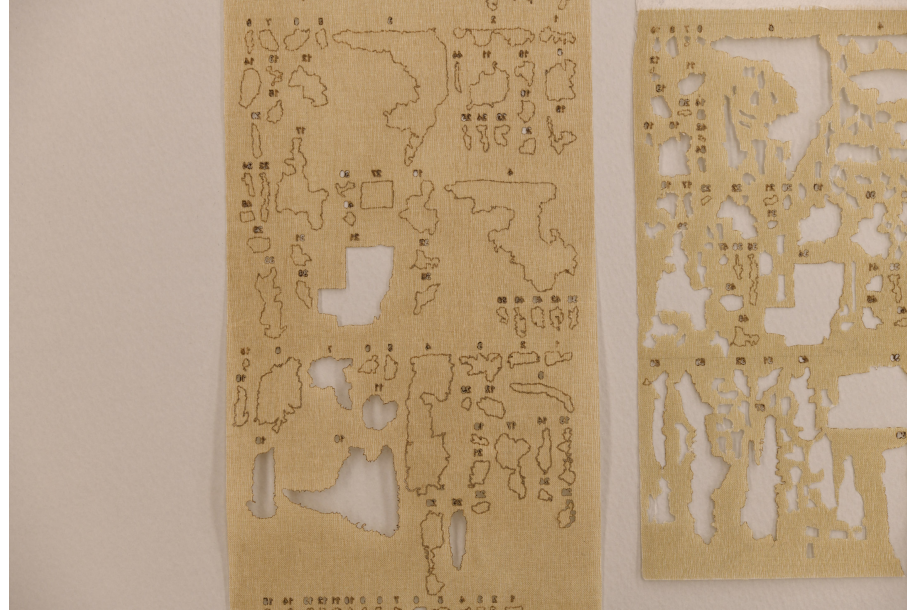
Area filter removes dust and the panel border. Remaining false positives are deleted with one click, in the same window. Review takes minutes.

The conservator decides what counts as a loss.

Vectorise, nest, laser-cut, fit



Cutting layout, SVG: numbered outlines (detail)



Laser-cut aged silk. Each piece carries its number.



Cut sheet over the painting. White: temporary hanji lining.

Pieces are packed by size with a 2 mm margin, and each outline can be fine-tuned in the software before cutting. The laser leaves a slight browning at the edge: the lining thickness and the laser settings control it, and a knife plotter cuts the same file cold.

From hours to minutes on a real painting

Myohyangsan Jeondo (묘향산 전도),
one of eight panels, 156 losses

3 h 43 min



manual tracing of 156 losses

10 min

detection and tracing by the software,
about 20x faster

Scans of about 250 megapixels, processed in chunks on a PC with 8 GB of RAM.

Applied afterwards to two panels of the Pyeongan screen: 806 and 1,003 losses detected.

Patent filed in Korea, KR 10-2026-0119526: Samsung Foundation of Culture, POSTECH, Korea Hydro & Nuclear Power.

Fitting is still by hand. Tracing and cutting are no longer the bottleneck.



Before: old backing removed, losses exposed



After: laser-cut aged silk fitted into the same losses

Myohyangsan Jeondo, same area of one panel, before and after infilling. Tone of the second photograph matched to the first.



... the next step development for fast condition survey

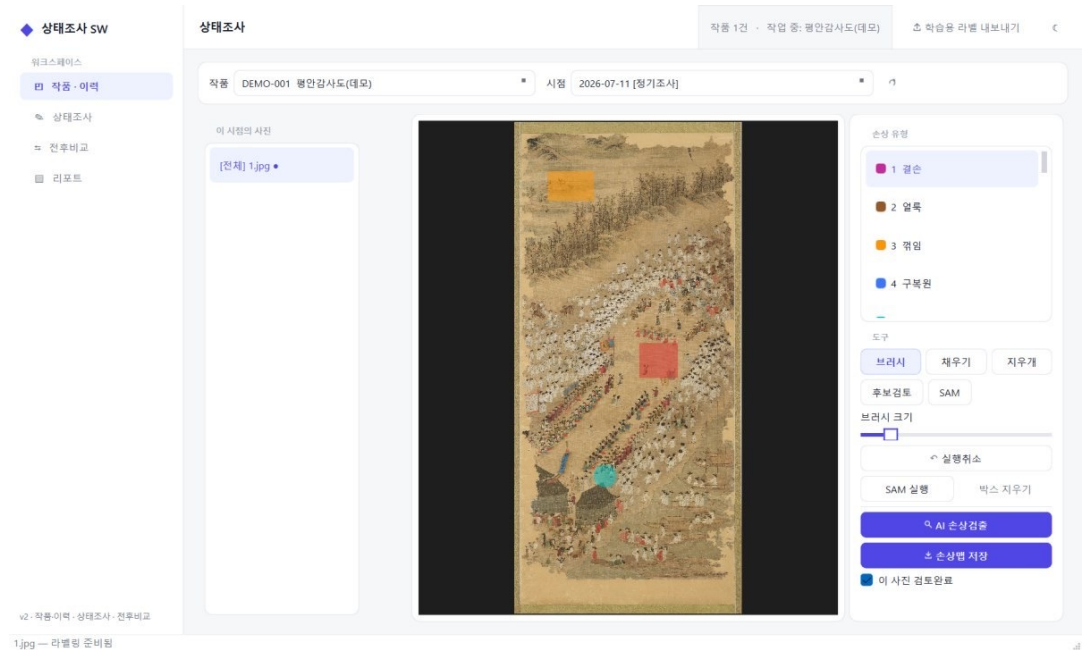
Our method works best after the old backing is removed for conservation work.

On the other hand, in condition surveys that are conducted on the mounted painting, without removal of the old backing, damages are much less obvious such as cracks, lifting, and stains.

Colour statistics alone are not enough there.

Next-step development:

- Deep-learning damage models trained on images taken before treatment
- Condition-survey software that collects conservator labels as it is used, so the data grows with every survey



Condition-survey software prototype (Korean interface). The AI proposes labels; the conservator checks and corrects them in the same window.



Another project: Accelerated aging of infill substrates

Why the infill must be aged

"No one sews a patch of unshrunk cloth on an old garment, for the patch will pull away from the garment, making the tear worse." Matthew 9:16 (NIV)

New fabric is stronger than a 200-year-old original. Under humidity cycles, stress concentrates at the boundary and the weaker side tears.

The infill must be weaker than the painting, so that failure is more likely in the replaceable part.

The silk precedent, and the gap

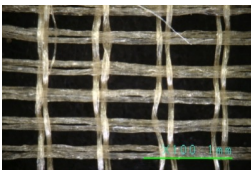
Japan, since the 1960s: electron-beam aged silk, now standard for national-treasure conservation. JAEA Takasaki practice: 300 to 2,300 kGy, reported as roughly 40 to 700 years of natural aging. Silk only.

Cotton: no established protocol. Cellulose, not protein, so the dose range and the evaluation criteria must be built again.

Current practice relies on sunlight exposure, which is hard to control and reproduce.

Programme, Phase 1 under way (June to October 2026)

Substrates	cotton first (a 19th-century cotton screen held by the Met), then silk and paper. Leeum-matched samples and commercial controls
Test ranges	electron energy 1.0 to 2.5 MeV; total absorbed dose 100 to 2,500 kGy, single or split into up to 8 irradiations; in air, ambient temperature
Measurements	SEM, FTIR, tensile strength, degree of polymerisation, crystallinity, colour ΔE, pH
Conservator grading	colour, feel and flexibility, pigment uptake, adhesion, cutting: pass or fail
Partners	Leeum, POSTECH, KAERI, Kyung Hee University; Ulsan University in discussion
Phase 1 outputs	a sample library by dose, a grading rubric, and a process window that links measurements to pass or fail



Leeum re-weaves silk to match the painting's weave, then ages it.



Summary



The treated screen on display at the Peabody Essex Museum, 2025. Photo: Peabody Essex Museum.

- Korean folding screens are historical records. On the screens we treated, the losses numbered in the thousands.
- A colour-statistics model, trained by a conservator in a few minutes, cuts tracing from hours to minutes. Laser-cut infills fit the losses.
- Phase 1 is under way to evaluate accelerated aging for cotton, silk, and paper infills.

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Damage Pipeline: Detect → Classify → Vectorize → Laser-Cut

1 Detect

Expert-trained color model

ROIs: expert drags ≥ 1 damage (hole) and ≥ 1 intact (paint) region

Feature: $x = [L, a, b, S]$ per pixel (CIELAB + HSV saturation)

Model: each ROI = one Gaussian component; μ and $(\Sigma + \epsilon I)^{-1}$, $\epsilon = 10^{-4}$

No EM, no mixing weights: trains instantly, deterministic

Scale: 2 MP chunks, $\leq \sim 64$ MB each $\rightarrow$ 39 MP+ on 8 GB RAM

2 Classify

Per-pixel Mahalanobis rule

Distance: $d_k^2(x) = (x - \mu_k)^T \Sigma_k^{-1} (x - \mu_k)$

Rule: damage if $\min_k d^2(\text{intact}) > \min_k d^2(\text{damage})$

Morphology: 3×3 elliptical close $\rightarrow 7 \times 7$ Gaussian blur $\rightarrow$ re-binarize > 127

Edge snap: Canny on L and b; mask boundary snapped to edges in a narrow band

Filters: min/max area; auto document boundary

3 Vectorize

Fragments to SVG

Contours: one per connected damage fragment

Simplify: Douglas–Peucker, $\epsilon = 0.9$ px $\rightarrow$ SVG path (M, L, Z)

Metadata: x, y, bbox, area, ID kept in session

Numbering: 300 px grid cells, left $\rightarrow$ right, top $\rightarrow$ bottom; re-number after review

Tiles: split captures merged, seam artifacts removed

4 Laser-cut prep

Skyline 2D bin packing

Pack: sort by area $\downarrow$; bbox at lowest skyline slot (best fit)

Rotate: 90° when it lowers height; new page when full

Sheet: A4/A3/A2/B4/custom; 1.5 mm gap against laser heat

Scale: enter one piece's real size (cm) $\rightarrow$ px-to-mm ratio

Output: numbered guide SVG + label-free cut SVG; collision-checked labels

Software architecture

GUI · PyQt6

MainWindow, SVG overlay & layout viewers, region selectors; QThread detection/analysis workers

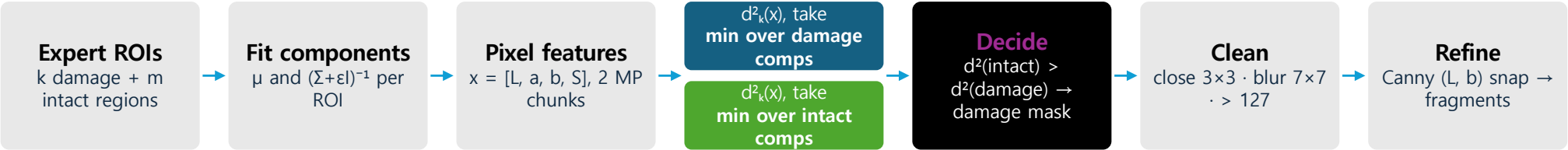
Core · detector.py

detect(), detect_with_filters(), analyze_regions(); component fit and Mahalanobis mask

Algorithm modules

extract_whiteness_based · spatial_numbering · create_cutting_layout (BinPacker2D Skyline) · nfp_packer (NFP polygon packing, collision check) · create_restoration_guide (coverage visual, CSV) · multi_image_processor (tile merge) · CLI workflow

Classifier Flow, Expert Review and Field Results



Expert review in the GUI

Toggle: click a fragment active/inactive (green/red outline)
Deselect Area: drag to bulk-exclude false hits such as the color chart
Navigate: search by ID, zoom/pan the full-resolution scan
Re-number: consecutive IDs over active fragments only
Session: save/load model, ROIs and active states
Example: 372 detected → 254 kept in 2–3 min → 3 pages of 150 × 100 mm

Why this design (vs. prior art)

Prior approach	Limitation	Here
Single-Gaussian Mahalanobis (Khelifi 2022)	unimodal; RGB only	many components; L, a, b, S
GrabCut (GMM K = 5 + graph cut)	EM + graph memory; slow at 39 MP	closed-form statistics; chunked
SAM / YOLO	merges adjacent holes; needs big labeled sets	per-fragment contours; no pretraining
GMM degradation masks (2025)	digital inpainting only	SVG + laser layout

Field result

~20× faster

Myohyangsan-jeondo, one face with 156 damage sites: 3 h 43 min manual tracing vs ~10 min from ROI selection to SVG layout

Laser-cut silk matched the hole outlines when laid over the painting

Baseline: Pyongan Gamsa-do restoration, ~10,000 losses, 3 conservators, ~4 months by hand

Multi-component in practice: 6 damage + 8 intact ROIs (bright upper and dark lower tones of one work) form one model, so damage in both tone zones is caught in a single pass, which a single Gaussian or single threshold cannot do.